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LYMPHOCYTOSIS AFTER ELECTRICAL CONVULSION

BY

JOSHUA CARSE and ELIOT SLATER

(RECEIVED 13TH SEPTEMBER, 1945)

Introduction

SEVERAL authors have reported changes in white cell count after artificially induced convulsions—Fattovich (1937, 1938), Blomquist (1938), Lemmi (1939), Horn (1939), Felici (1940). Unfortunately only two of these papers are accessible to us. The first paper of Fattovich is a very brief communication, unsupported by case records or figures, in which he states that within the first half-hour after cardiazol shock in the schizophrenic there is an increase in the monocytes, a diminution of neutrophils, and in some cases a slight diminution in lymphocytes; later on there is an increase in neutrophils, and a diminution of lymphocytes, and eosinophils. Horn discusses his results with azoman, cardiazol and neospiran on 10 schizophrenics, and quotes in tabular form the findings made with six of them. His readings are made at time 0 and after 1 and 2 hours. He finds diminution of basophils, eosinophils, and lymphocytes, no change in the monocytes, and big increases in neutrophils, especially immature forms. He attributes these changes not to the drugs, but to autonomic stimulation by the convulsion. In support of his views he quotes the observations of Georgi and Wechsler on the blood picture in insulin shock. Blomquist and Lemmi report their findings with metrazol, and Felici his with electrical shock; it is to be regretted that the war has made these papers inaccessible.

The investigation that is described below was carried out by one of us (J. C.) without the knowledge of the work of these authors, and was begun in 1937. It was thought desirable to record the findings within a few minutes of the convulsion, and the following technique was used. The laboratory technician was present in the theatre before treatment was begun, and actual and differential cell counts were made on the fasting patient. Throughout the tests capillary blood from the finger-tip was used, and for every count 200 white cells were counted. The time at which the electrical convulsion was given was noted and cell counts were made at intervals of 3 minutes for the first hour and again at 1½ and 2 hours. In the series of 50 patients under consideration in this paper, however, counts were only made at 3-minute intervals for 21 minutes, and at 30, 45, and 60 minutes, as most of the more remarkable changes were observed in the first quarter of an hour.

Results

Immediately after the convulsion, during the next 15 minutes, there are violent fluctuations in the number of neutrophils. In one of the 50 patients observed there was a rise in their number from 3,600 at time 0 to 10,300 at 6 minutes. But it is almost as common for the number of neutrophils to drop as to rise; one of the patients showed at time 0 3,400 neutrophils; at 3 minutes after the convulsion 1,800; at 6 minutes 3,500; and at 9 minutes 6,700. The fluctuations are rapid and entirely irregular. When mean values of the 50 observations at every time interval are calculated no consistent rise or fall is found; and analysis of variance shows that such differences as are seen are not significant. There is, however, a highly significant rise in the standard deviation of the observations from 574 at 0 minutes to an almost threefold value of 1,692 at 6 minutes, corresponding to the greatly increased range of individual variation. Furthermore there is a significant tendency for the females to score on the average higher values than the males.

It is otherwise with the lymphocytes. Although these also fluctuate sharply after the convulsion, there is a systematic tendency for their number to rise to a maximum at the sixth minute, and thereafter to decline more gradually back towards the norm. Analysis permits of no doubt that this tendency is a meaningful one, and not to be accounted for by experimental error or by random variance from other causes.

In view of the interest of this finding, it was thought desirable to test for differences in the degree of lymphocytosis when patients were subclassified by sex and diagnosis. Of the 50 patients 30 were schizophrenic or paraphrenic, 15 male and 15 female, and 20 suffered from other mental disorders predominantly involutional melancholia, 9 male and 11 female. The results of the subclassification are given in Table I. It will be noted that in males the rise in number of lymphocytes is more marked than in females, and that it is more marked in the schizophrenics than in the others. The significance of all these findings was tested by analysis of

TABLE I

Time (minutes)	Mean number of white cells per cubic millimetre							
	Neutrophils			Lymphocytes				
	All groups	Male	Female	All groups	Schizophrenics		Others	
					Male	Female	Male	Female
0	3,590	3,440	3,730	1,420	1,430	1,470	1,440	1,310
3	3,450	3,260	3,630	2,050	2,130	2,050	2,090	1,840
6	3,700	3,500	3,880	2,600	2,840	2,690	2,700	2,040
9	3,650	3,560	3,730	2,350	2,910	2,030	2,050	2,200
12	3,360	3,130	3,570	1,910	2,210	2,000	1,620	1,600
15	3,710	3,350	4,040	1,890	2,230	1,830	1,980	1,390
18	3,540	3,380	3,690	1,590	1,830	1,480	1,470	1,360
21	3,440	3,360	3,520	1,570	1,860	1,550	1,650	1,290
30	3,540	3,570	3,510	1,450	1,570	1,580	1,430	1,120
45	3,620	3,490	3,740	1,470	1,490	1,550	1,390	1,380
60	3,610	3,510	3,700	1,440	1,490	1,580	1,310	1,360

Capillary white cell counts at stated number of minutes after electrical convulsion.

TABLE II

Source of variance		Neutrophils:		Lymphoctyes:	
	Degrees freedom	Sum of squares	P	Sum of squares	P
1. Total variance	527	54843·62		29334·91	
2. Variance attributable to differences in—					
(*a*) Time of observation..	10	669·47	>0·05	8055·47	<0·001
(*b*) Sex	1	1251·84	<0·001	413·05	<0·001
(*c*) Diagnosis	1	0·63	>0·05	653·49	<0·001
3. Residual variance between individuals	44	25159·14	<0·01	5161·89	<0·001
4. Variance attributable to interaction between—					
(*a*) Time and sex..	10	525·10	>0·05	340·77	>0·05
(*b*) Time and diagnosis	10	548·62	>0·05	210·09	>0·05
(*c*) Sex and diagnosis	1	84·28	>0·05	0·30	>0·05
(*d*) Time, sex, diagnosis	10	1031·18	>0·05	672·50	<0·05
5. Error variance	440	25573·36		13827·35	

Analysis of variance. Probability (P) is ascertained from the variance ratio, F. For this analysis two female non-schizophrenic patients, chosen at random, were omitted, in order to make the numerical relationships orthogonal, when the patients were subclassified by diagnosis and sex.

variance, the mode of collection of the data permitting this to be carried out with an unusual degree of completeness (Table II). The analysis establishes the statistical significance of all three findings—the occurrence of a lymphocytosis, and of sex and diagnostic differences.*

As perhaps might have been expected, in view of the findings, neutrophil and lymphocyte counts were only very loosely correlated. The correlation coefficient has a small but significant value of $+\cdot10$ ($P<\cdot02$).

Discussion

We do not wish to enter into a theoretical discussion of these findings. According to Wiggers (1944), a neutrophil leucocytosis is well known after convulsive seizures, hard exercise, and severe pain, the changes being attributed to release of leucocytes trapped in unused capillaries, especially in the lungs and liver. Lymphocytosis, when it occurs, is attributed to an increased flow of lymph; it is produced in adults by actinic radiation, exposure of lymph nodes to X-rays, the effect of dry heat and high altitudes. It is difficult to see how mechanisms operative in these circumstances should also be the ones involved after electrical convulsion. We would agree with Horn in attributing the leucocyte changes in general to a disturbance of central regulation of the autonomic system. A point of great interest is that the lymphocytosis is significantly greater in the schizophrenic patients. Further discussion of this would require an advance in our knowledge of the physiology of schizophrenia.

* The effects of age had also to be taken into account. The mean age of the schizophrenics, male and female, was 33 years, range 15–55, and of the non-schizophrenics, both male and female, was 52, range 26–70. The regression of lymphocyte count on age, diagnosis held constant, was calculated but found to be non-significant.

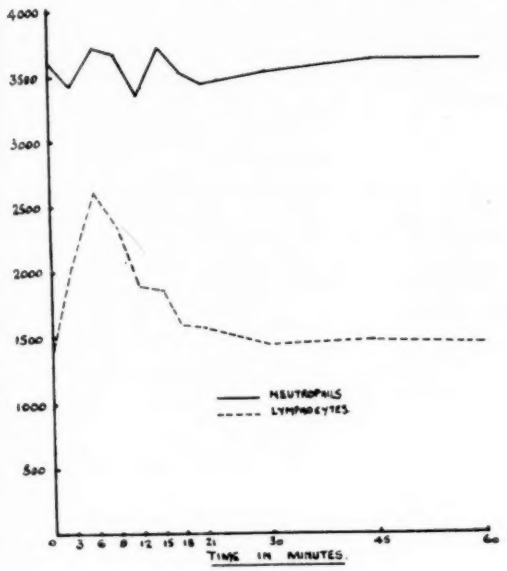
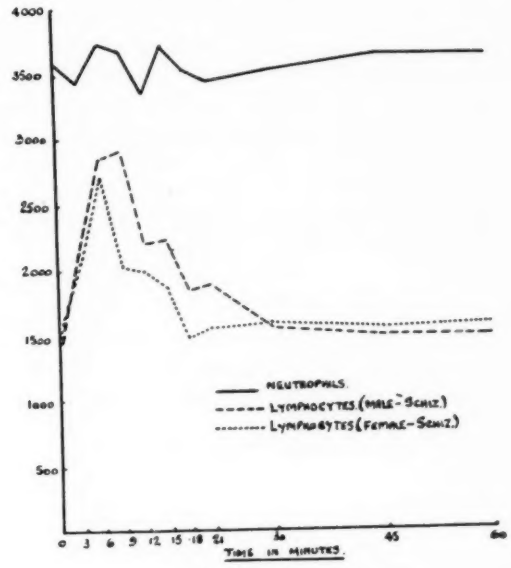


FIG. 1.



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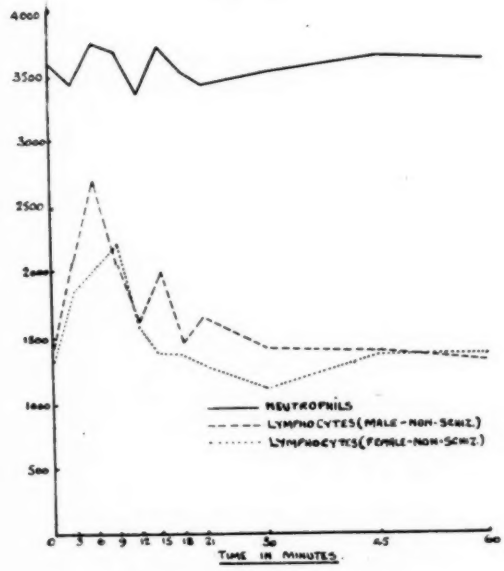

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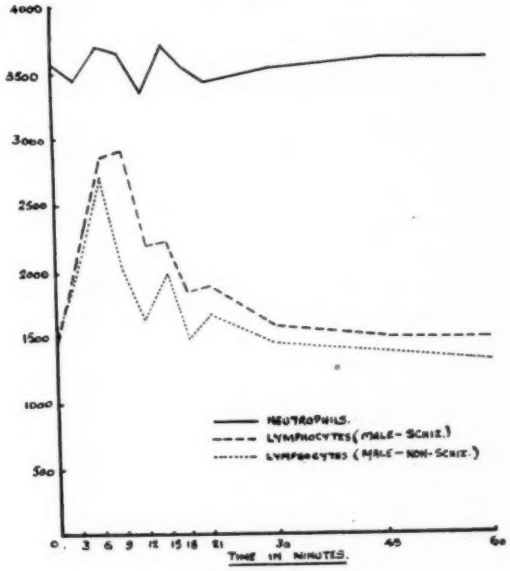

FIG. 4.

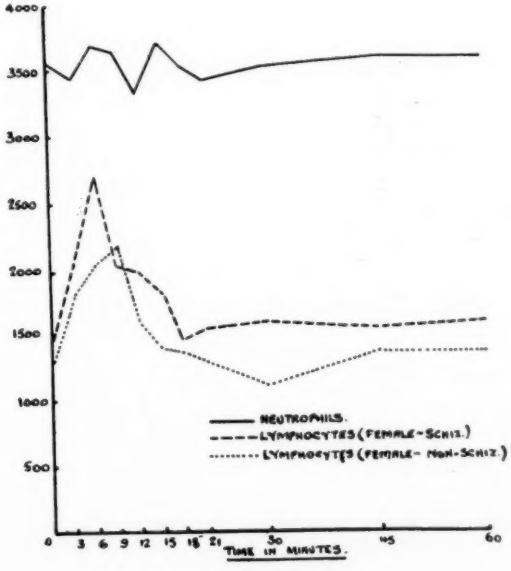

FIG. 5.

Our finding adds but one to the increasing list of functional disturbances that have been found in this disease. According to Hoskins (1945), schizophrenics show among other things differences from the normal in the regulation of body temperature, blood pressure, oxygen, and glutathione metabolism, reaction to insulin and to sugar. It is impossible as yet to build these manifold jig-saw pieces into a coherent picture.

Summary

After electrical convulsion there are in the first 15 minutes sharp fluctuations in the number of neutrophil leucocytes, which show no systematic rise or fall. There is a systematic rise in the number of lymphocytes in the same time, greater in males than in females, and in schizophrenic than in non-schizophrenic patients.

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THE RELATION BETWEEN THE ELECTROENCEPHALOGRAM AND MUSCLE ACTION POTENTIALS IN CERTAIN CONVULSIVE STATES

BY

G. D. DAWSON

The David Lewis Epileptic Colony and Neurological Research Unit, National Hospital, Queen Square

(RECEIVED 25TH FEBRUARY, 1946)

Introduction

STUDY in man of the relation between the occurrences in the electroencephalogram (EEG) and the muscular jerkings in convulsive states has been limited. Possibly this has been due to the difficulty of anticipating the time of onset of seizures sufficiently often, and with sufficient accuracy. In two types of case this difficulty may be overcome. The first is that in which myoclonic jerkings occur over a period of one or two hours as a prodrome of a major convulsive seizure and the second that in which a wave and spike discharge in the EEG lasts for 24 to 48 hours and is accompanied by muscular jerkings. It is the purpose of this paper to describe the results of repeated examinations of patients with these conditions.

Gibbs, Davis and Lennox (1935) showed that in those patients with epilepsy in whom a discharge of wave and spike form appeared in the EEG during a seizure, minor muscular jerkings might occur at the same rate as that of the repetition of the wave and spike complex. They also reported that in the clonic stage of a major convulsive seizure the jerkings of the muscles occurred in time either with slow waves or groups of spikes in the EEG. In neither case was fuller analysis of the temporal relations of the EEG waves and the muscular movements described. Jasper and Andrews (1938) by recording the EEG, muscle action potentials and movements studied the relations between wave and spike discharges in the EEG and the muscular jerkings during minor epileptic seizures. They found that when wave and spike discharges in the EEG were provoked by overbreathing, a burst of muscle action potentials was often associated with each wave and spike complex. In some subjects this correspondence did not occur and from this they concluded that in certain circumstances the control of the motor functions concerned might be taken over by subcortical centres. Recording of the EEG and muscle action potentials has been used by Strauss and Landis (1938) to compare the features of spontaneous convulsions and those produced by cardiazol. They used the method to time the contractions of flexor and extensor muscle groups but they give few details of their results in this connection. During the severe muscular jerkings which occur in myoclonic epilepsy Grinker, Serota and Stein (1938), who studied a group of patients with a hereditary form of this complaint, were able to show that a close correspondence existed during the jerkings between groups of spike-like discharges in the EEG and the muscle action potentials. They recorded the muscle action potentials only from the biceps muscle of the arm and no simultaneous recordings from antagonistic muscle groups were reported. Their records would not allow accurate measurements of the time relations of the individual spikes of a group and any particular phase of the muscular jerkings. Confirmation of the findings of Grinker *et al.* is given by Jasper (1941) and Gibbs and Gibbs (1941) who also describe groups of spike-like discharges in the EEG in time with the myoclonic jerkings, but in neither case are any facts added about the time relations of the spikes and the jerks.

The present investigations have been made on two types of case with myoclonic symptoms during epileptic states. The results of simultaneous recordings during myoclonic attacks of the EEG and muscle action potentials in flexor and extensor muscle groups of the limbs will be described.

Material

The subjects studied have been selected from amongst the 450 residents at the David Lewis Epileptic Colony. In this number of habitual epileptics five patients have been found in whom severe myoclonic jerkings are a prominent symptom and one patient in whom mild myoclonic twitching in the limbs accompanies a discharge of wave and spike form in the EEG that may last up to 48 hours. Of the five patients with severe myoclonic jerkings it has been possible to predict the onset of seizures to within a few hours in two patients (337 and 407) and these have been studied repeatedly. The length of the seizure in the patient with the wave and

spike discharge makes recording easy after the seizure has started and in this subject (377) also repeated examinations have been made.

The two patients with severe myoclonic jerkings (337 and 407) are strictly comparable as regards symptoms with those described by Grinker *et al.*, except that they have no history suggesting a familial incidence of the complaint, and that their condition is either stationary or only slowly progressive in its severity. These patients suffer from jerkings of the muscles which are sufficiently powerful, when they occur in the legs, to cause the subject to fall heavily to the ground; or, when they occur in the arms, to cause the subject, if he is holding some quite heavy object, to throw this over his head. In neither of the patients are the jerks, which are extremely brief, associated with detectable changes in consciousness. Usually the jerks occur at progressively shorter intervals over a period of 1 to 2 hours until finally one of them passes with little pause into the tonic stage of a major convulsive seizure. Occasionally after becoming more frequent the jerks occur less often and then cease. When this happens, if the patient goes to sleep before the jerks have disappeared, on his reawakening they may reappear, increase in frequency as before, and terminate in the usual major seizure. Any excitement or attempted exertion tends to aggravate the jerkings and may precipitate the terminal seizure. Therefore, if an adequate time for examination is to be gained, the subject must relax as completely as possible when the jerkings begin. Although the period between the onset of the jerks and the final seizure in this type of case is rarely more than 2 hours, it has been possible with the excellent co-operation of the subjects and their friends in the Colony, who helped the subject to the laboratory immediately the jerks began, to examine these two patients repeatedly for periods of 1 to 1½ hours before their major seizure.

The third patient (377) who has been examined repeatedly is one who, besides having major convulsive seizures, is subject to attacks of mild muscular jerkings which last for a period of up to 48 hours and are associated with a continuous wave and spike discharge in the EEG. At the beginning of the attack there is slight clouding of consciousness and the twitchings of his muscles are diffuse and irregular. After about twelve hours the clouding of consciousness disappears and the jerkings become synchronous in all parts of the body and regular at about three per second. If untreated this state may continue for a further 24 hours and then the jerkings and the wave and spike discharge will cease spontaneously and suddenly. For several days before a spontaneous attack, attacks of jerking may be provoked by overbreathing. For several days after a spontaneous attack the same amount of overbreathing, or a greater amount, will produce no outburst. The jerkings of this patient have none of the violent nature of those occurring in the type of case described above and do not monopolise the entire voluntary power of the muscles concerned. Once the initial stage of diffuse twitching has passed off and the jerkings have become regular, the subject is able to walk around, talk, and dress himself, though all these activities have the jerkings superimposed on them.

Methods

Records of both the EEG and muscle action potentials have been made with inkwriting oscillographs and resistance-capacity coupled amplifiers. Four channels have been available and the usual arrangement has been to record the EEG from the scalp with two of these channels and bipolar electrode placements over frontal, motor, and parietal regions of one side of the head; the other two channels being used to record from the flexor and extensor muscles in the thigh or upper arm of the opposite side. On other occasions the EEG has been recorded from the motor areas of the two sides and the muscle action potentials from the flexor or extensor muscles of the two sides in the upper arm or thigh. The patients have been examined whilst lying in the supine position on a blanket covered bed. This is important if the friction artefacts are to be avoided which occur during convulsive movements when a leather-covered couch is used.

OSCILLOGRAPHS.—The oscillographs used in this work are copies of those designed by Mr. A. M. Grass of Boston, who kindly gave permission for them to be made in this country as the shipping position at the time this work was started made importation impossible. The writers have a performance strictly comparable with that of the Grass type with the exception that 20 per cent. of the maximum linear amplitude of deflection has been sacrificed to allow a small increase in the natural period of the system; this lies between 70 and 80 c/s, and is critically damped. The importance that is attached to the shape of waves that have components both above and below the resonant frequency of the recording system must be limited. The reason for this is that although the system may have a good response to the higher frequency components of a complex waveform, when these fall above the resonant frequency of the writer they may be shifted in phase in relation to any lower frequency components that fall below the resonant frequency. When such mutual phase shifts of the components of a complex wave occur the shape of the wave will be altered. Though the shape of a wave of the type mentioned may not be recorded accurately, differences in the shapes of waves will remain of significance with any one recording system. In spite of these relative inaccuracies at the higher frequencies it has been necessary to tolerate the inkwriting oscillographs rather than to use a more accurate recording system. Such a system with cathode ray oscillographs, giving four simultaneous records, has been available and has been used to monitor and check the performance of the writers in recording waves with periods of less than 10 to 12 milliseconds, which is about their extreme upper limit of accurate recording. Otherwise this second recording system has been of little value in these studies on account of the long intervals that may occur between the myoclonic outbursts which make photographic recording prohibitively costly. With the inkwriting oscillographs recording paper speeds of 4 and 8 cm. per second have been used during the periods when jerkings were expected and 2 cm. per second at other times. Time scales are indicated in seconds at the top of the records, and also in some cases, at the faster recording speeds, by a 50 c/s trace or a 0·1 second mark in the centre of the record. Calibration of amplification is indicated in microvolts (μV.) or millivolts (mV.) at the right-hand end of the records. The records throughout read from left to right.

AMPLIFIERS.—The amplifiers used are of conventional design and give the same amplification for all frequencies from 1 to 100 c/s, with optional reduction of the

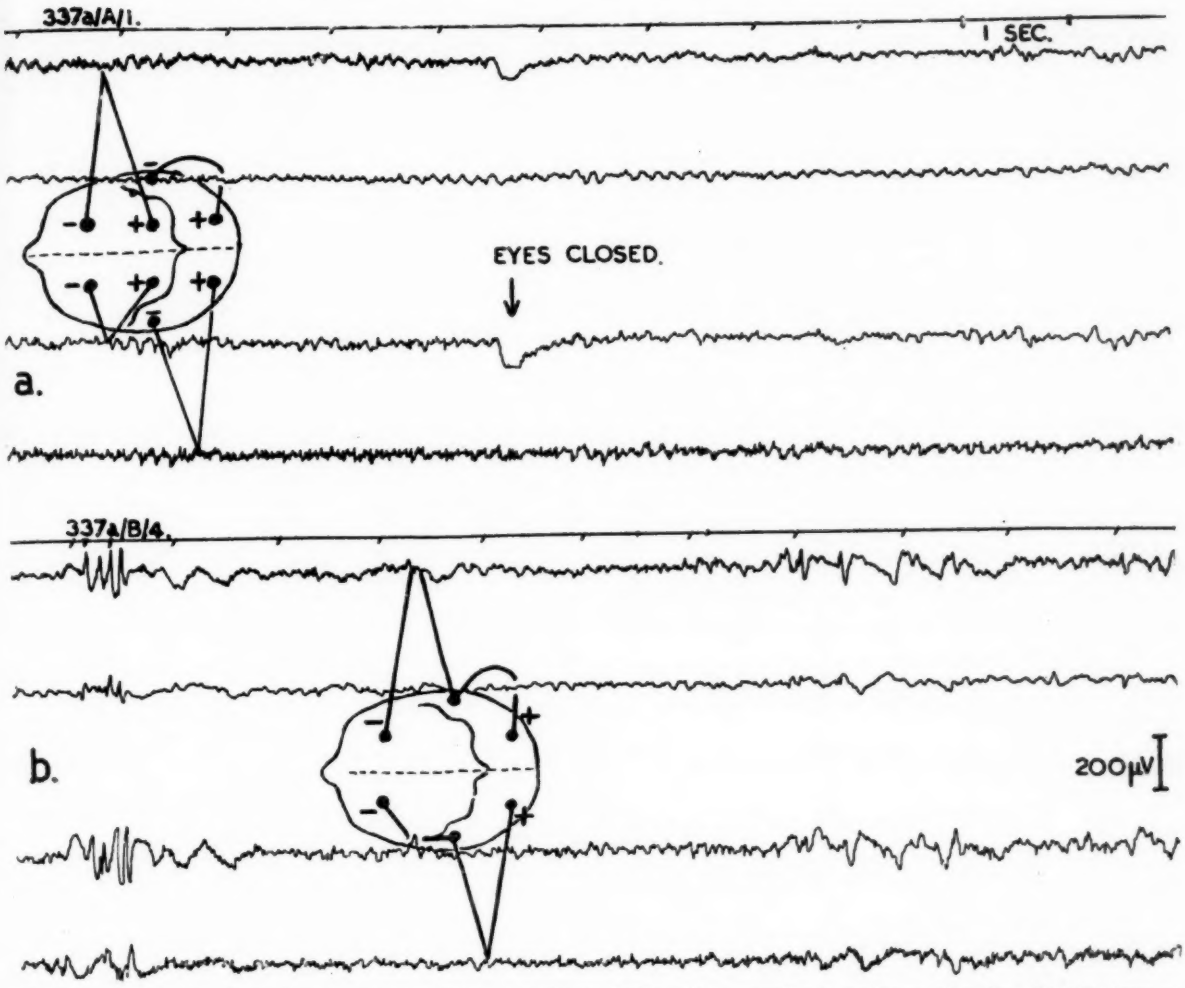

FIG. 1.—EEG records between seizures from a patient (337) with myoclonic epilepsy showing (*a*) rhythms at 6 to 7 c/s unaffected by closing the eyes, and (*b*) groups of spikes and slow waves. In this and all following records the time scale at the top indicates one-second intervals. The + and − signs at the electrodes in all the head diagrams indicate that a potential difference such that the electrode marked + is positive with respect to that marked −, will cause an upward deflection in the record.

response to the higher or lower frequencies. The input connections are symmetrical with respect to earth and lead to an input circuit of the type described by Toennies (1938). In later experiments this circuit has been replaced by one designed on the principle described by Buchthal and Nielsen (1936) and Offner (1937), which has advantages when followed by pushpull amplifiers such as those used to drive the inkwriting oscillographs. With this circuit it is possible to record simultaneously from scalp and a limb without the electrocardiogram appearing in one or both records; it also prevents the muscle action potentials, which may be as large as 10 or 20 mV., from appearing in the EEG record, even when this is small and is being recorded with a high amplification.

The standard amplifier setting used for recording the EEG gives an equal response to all frequencies between 2 c/s and 50 c/s. When the muscular jerkings are very severe low frequency movement artefacts may become a serious nuisance and under these conditions the response is kept constant from 50 c/s down to 20 c/s and then attenuated by 30 per cent. at 10 c/s. The records taken with these last constants cannot be used for direct comparison of waveforms with those in records taken at the standard setting on account of the mutual phase shifts of the components of complex waves that occur; however, changes of the shapes of waves that occur in any one record remain significant. For recording the muscle action potentials amplifier settings are used which give an equal response to all frequencies between 20 c/s and 50 c/s. Below 20 c/s the response is attenuated by 30 per cent. at 10 c/s. Above 50 c/s the response is increased by 10 per cent. at 80 c/s and then falls steadily and is attenuated by 80 per cent. at 150 c/s. The rise of the response at 80 c/s has been allowed on account of the considerable extension of the response to higher frequencies which it makes possible.

ELECTRODES.—The electrodes used to pick up the potential differences from the scalp have in all cases been similar to those described by Walter (1936). These consist of a gauze-covered sponge pad, 1 cm. diameter, soaked in saline solution and supported on a chloride-coated silver tube. They have been held in place on the scalp by a rubber and whalebone cap. On account of the violence of the subject's movements during attacks smaller electrodes held in place by collodion might have been preferable. However, the time saved in application of the saline pad type of electrode has been of great importance and they have not in fact been found, when properly applied, to cause any significant artefacts.

For recording the muscle action potentials large surface plate electrodes, 2·5 by 3·5 cm. in size, making contact through Cambridge electrode paste and held in place by rubber straps have been used. Two such

plates separated by 1·5 to 3 cm. have been applied to each muscle group to be studied. These large contacts have been used in preference to needle electrodes for two reasons. First, the needle electrode was introduced by Adrian and Bronk (1929) because of the very restricted space from which it picks up potential differences. Since these studies are concerned with the behaviour of muscle groups as a whole this restricted pick-up is undesirable. Secondly, the risk of damage to the muscle, or breakage of the needle during the jerks, is so high that to use such an electrode has been considered an unwarranted tax on the co-operativeness of the subjects. The chief disadvantage of the big surface plate electrodes used is the large area from which they pick up potential differences. In practice the localization of pick up given by these electrodes has been found to be satisfactory for this work. That is to say, when flexor muscles in the thigh or upper arm are contracting no potential differences of significant size appear in plate leads on the extensor aspect of the limb at the levels of amplification used in these studies. The same applies with regard to electrodes on the flexor muscles in the upper arm when the extensor muscles are contracting. In the thigh the muscle masses are less favourably disposed. When the quadriceps extensors are contracting action potentials may appear in plates over the hamstring muscles. These potentials are about 10 per cent. of the size of the action potentials picked up by plates, with a similar separation between them, applied over the contracting muscles themselves. Fortunately the order in which the potentials have been found to appear has made it possible to exclude this degree of spread from being important.

Results

1. Myoclonic Epilepsy

INTERSEIZURE RECORDS.—The two subjects who have severe myoclonic jerkings as a prodrome to their major convulsions show both similarities and differences in their resting EEG records. Both subjects show a bilateral discharge from frontal, parietal and occipital regions at 6 to 7 c/s which is unaffected by opening or closing the eyes. In one case (337) this discharge is rhythmical and rarely broken up by slower rhythms (Fig. 1 (*a*)). In the other case (407) the discharge is very irregular and is broken up by continuous slower discharges of small amplitude at frequencies down to 4 c/s (Fig. 2 (*a*)). Both subjects show outbursts of high voltage slow activity at 2 to 3 c/s, but these are larger and more common in the second case (407).

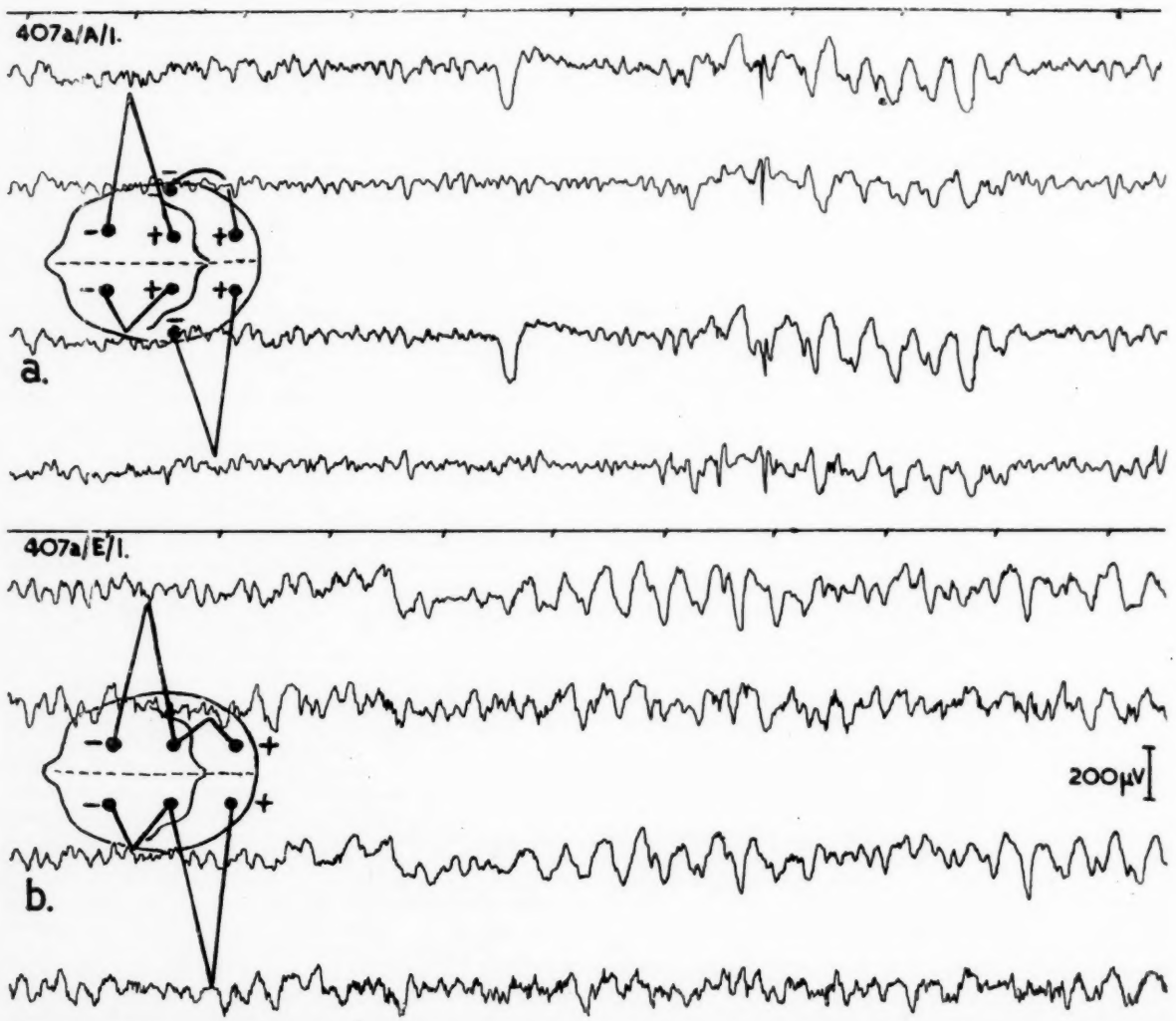

FIG. 2.—EEG records between seizures from a patient (407) with myoclonic epilepsy showing (*a*) greater amount of slow activity at 2 to 4 c/s than in the records of Fig. 1, and (*b*) effect of overbreathing in this case.

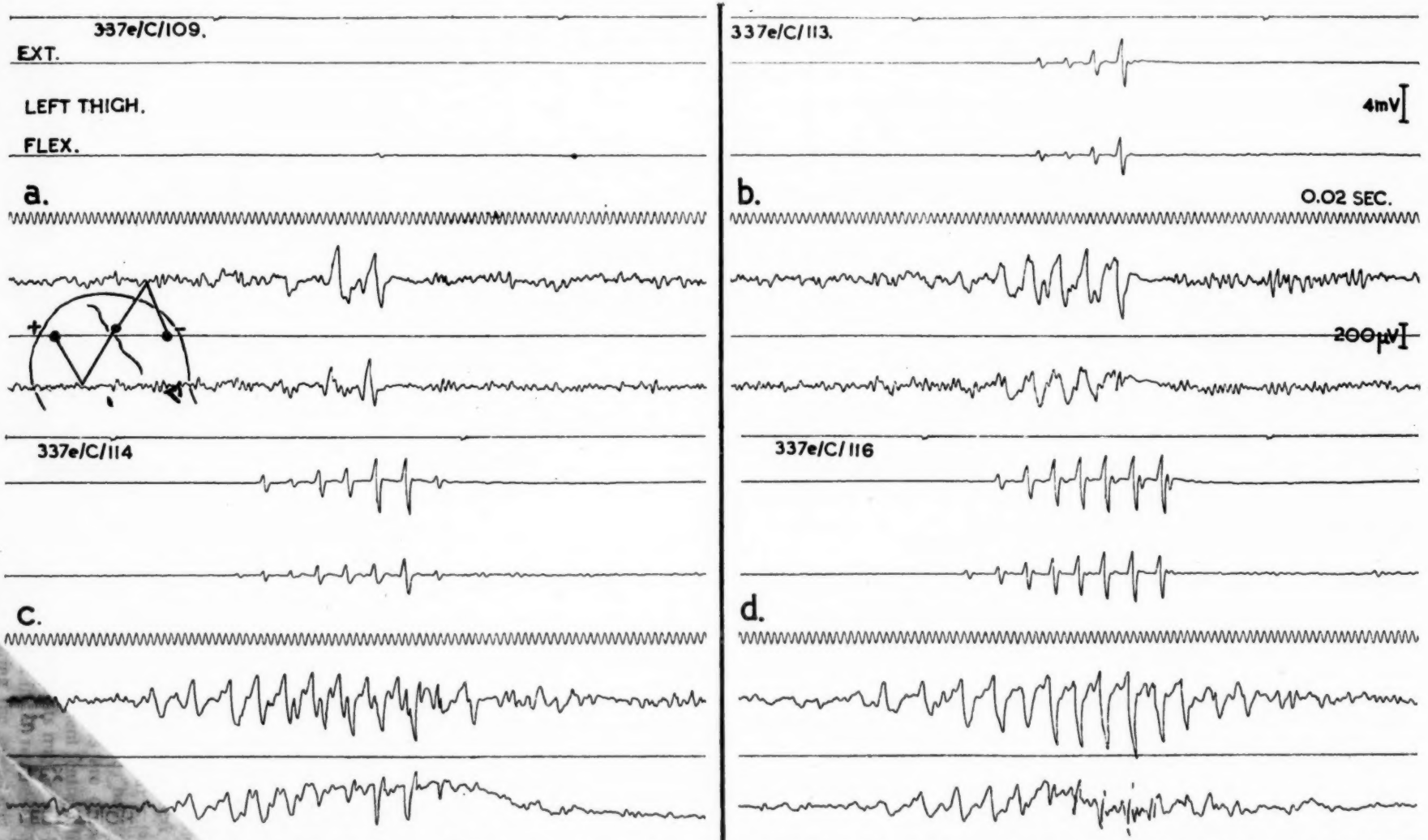

FIG. 3.—The upper two traces, marked EXT. and FLEX. record the muscle action potentials picked up from surface plate electrodes on the extensor and flexor aspects of the thigh. The two lower traces show the groups of spikes occurring in the EEG during episodes of myoclonic jerking. The calibrations on (*b*) apply to all the records.

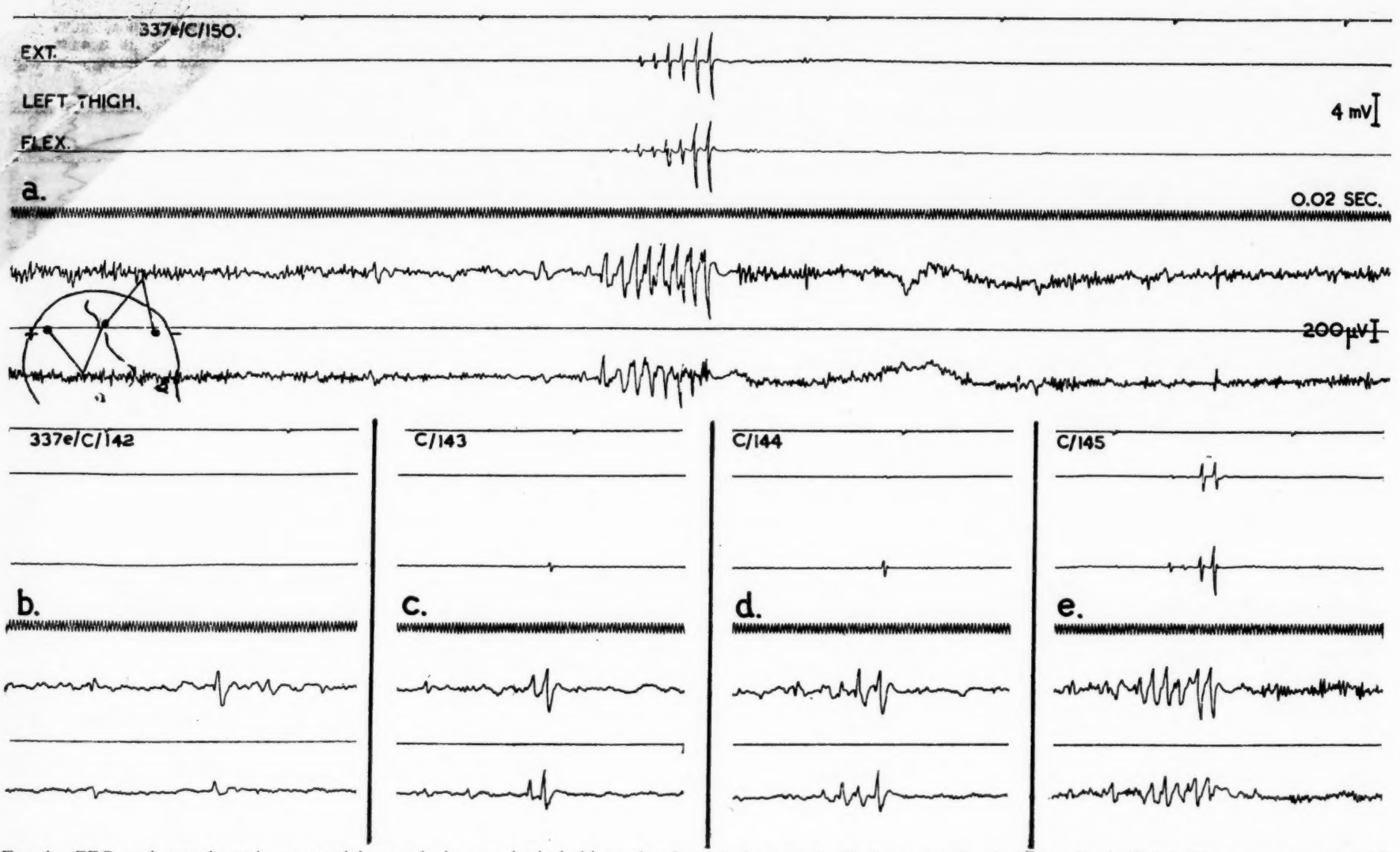

FIG. 4.—EEG and muscle action potential records in myoclonic jerkings showing (*a*) the muscle discharge starting in larger size in flexor than extensor groups of muscles and recruiting throughout the spike discharge in the EEG. A brief silent period follows the spike burst in the EEG. (*b*), (*c*), (*d*), and (*e*) show sections of a continuous record with 8-second intervals between them with corresponding increases in the number of EEG and muscle discharges.

These slow waves are largest in the frontal regions and may be accompanied by discharges of single or multiple spikes (Figs. 1 (*b*) and 2 (*a*)). In the quiescent periods muscular jerkings do not accompany these spikes. In the first case during overbreathing no effect on the slow waves is seen, but in the second case the slow waves are greatly increased in number (Fig. 2 (*b*)). In neither case has overbreathing been found to affect the frequency with which the groups of the spikes occur. The discharges present in these two cases are usually symmetrical on the two sides of the head.

RECORDS DURING SEIZURES.—During the episodes of jerking the EEG takes on an unusual and highly characteristic appearance. In this state brief groups of spikelike discharges occur at a frequency of 8 to 13 per second. The term spike will be used to describe these waves since they appear sharp at slow speeds of recording, though at the higher speeds used for measuring time relations they often lose much of their spikelike character. The spikes in the EEG may occur singly or in groups (Fig. 3 (*a*) to (*d*)). Although the spikes are usually larger in frontal than in precentral leads no case of jerking occurring synchronously with the spikes in the EEG has been seen when they have not appeared in the precentral leads. The duration of the EEG spikes is variable from about 25 to 75 msec. and is related to the placing of the electrodes with respect to the potential gradients on the scalp, and to the place of the spike in its group (Fig. 3). Over the duration of one burst the shape of the spikes changes in a way that tends to repeat itself in any one subject. The first phase of the potential change is surface negative and this is followed by a second phase that is surface positive. Sometimes a small surface positive change precedes the surface negative one (Fig. 4 (*b*) and (*d*)), but this is not constant. Towards the end of the burst the discharge appears as a short duration surface positive wave alone, or a rectangular surface negative wave. This change of shape may be due either to a movement of the origin of the potential difference with respect to the electrodes or to an actual change in the form of the potential difference. Which of these alternatives is the correct one cannot be decided in the absence of fuller studies of the potential distributions in the attacks. Following the spike burst there is usually a " silent period " of 0·1 to 0·5 sec. during which electrical activity falls to a minimum before returning to the same level that it had before the spike burst (Figs. 3 (*a*) and (*b*), and 4 (*a*)).

Associated with these discharges there occur the massive muscular jerkings found in this type of myoclonic epilepsy. With the amplifications used no muscle action potential or detectable muscular jerk has been found to accompany a single isolated spike in the EEG. Two spikes are usually accompanied by a minimal action potential in flexor muscles alone, whilst when a longer burst of spikes occurs action potentials most commonly appear first in the flexor muscles, follow in the extensor muscles and recruit steadily up to the end of the spike burst, then cease suddenly. A series of records in Fig. 4 (*b*), (*c*), (*d*), and (*e*), shows a progressive increase in the number of spikes in four consecutive bursts, with a corresponding increase in the number and size of the muscle action potentials. The length of the " silent period " or period of " extinction " after the spike burst also increases with the number of spikes in these records. The sections shown in Fig. 4 (*b*), (*c*), (*d*), and (*e*), are parts of a continuous record with intervals of 8 seconds between them in which no other equally large paroxysmal disturbances occur. They suggest a rapid and progressive increase in the cerebral abnormality over a period of 30 seconds. Once both the flexor and extensor muscles are contracting their action potentials are, within the accuracy of the measurements possible with these methods, apparently synchronous and without any sign of reciprocal innervation.

It was stated above that when a single isolated spike occurs in the EEG it has not been seen to be accompanied by a muscle action potential or clinically obvious muscular contraction. However, if the single spike follows within about 1·5 or 2 seconds of a previous burst of spikes, apparently some of the facilitation that has been built up during the burst remains, and a jerk and action potential, such as that indicated by the arrow in Fig. 5, may occur in the flexor muscles alone. For an extensor discharge to occur with a single spike it seems to be necessary that the interval between that spike and a preceding burst shall not be more than 0·5 seconds. If a break in the spike discharge in the EEG occurs, when the discharge restarts there has been a greater decay of facilitation for extensor than for flexor mechanisms. The records in Fig. 6 show that after an interval of 0·3 seconds the facilitation for the flexors has fallen little, and the muscle discharge restarts at the size at which it ceased (Fig. 6 (*a*)), or reduced by 50 per cent. (Fig. 6 (*b*)). For the extensors, however, the facilitation has apparently decayed to a greater extent, as the first of the succeeding discharges is much smaller than the last of the preceding ones. Some facilitation for the extensors remains, since the action potentials recruit more rapidly than in the initial burst. Measurements of the delay between the beginning of the EEG disturbance and the muscle action potential suggest a value for this not less than 15 and not more than 40 msec. These measurements, however, have to be accepted with caution for several reasons. First it is only in records such as those of Figs. 3 (*a*) or 4 (*c*) or (*d*), that it is possible to decide where the EEG disturbances begin, and secondly it is difficult to be sure that the particular EEG spike used as a reference is associated with a particular muscle action potential. Higher recording rates help little, as it is found that when the waves are opened out by this means they have no salient features from which more accurate measurements may be made.

One point of interest in the records of the muscle action potentials during the myoclonic jerkings is

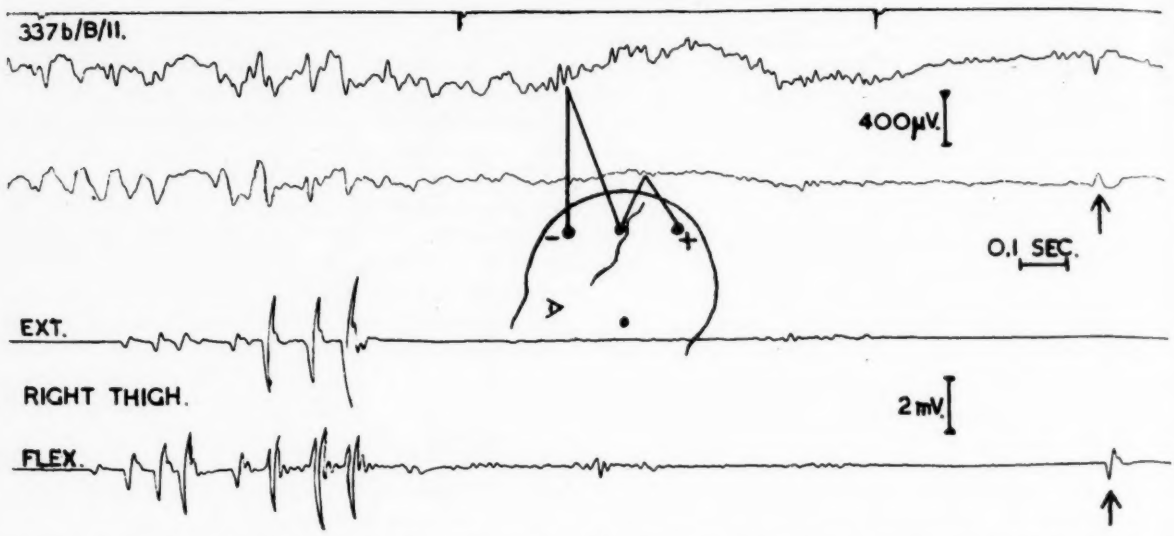

FIG. 5.—A single spike discharge in the EEG, marked by the arrow in the record, is accompanied by a muscle discharge if it follows within 2 seconds of a previous spike burst, cf. Fig. 4 (*b*) where a single spike not following a previous burst is unaccompanied by a muscle discharge.

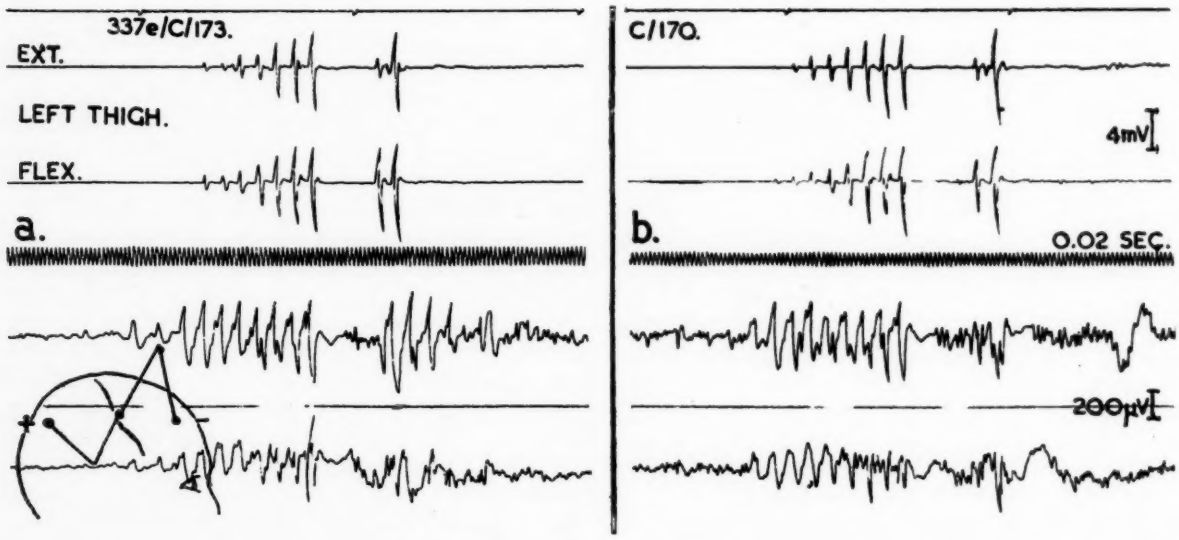

FIG. 6.—Following a break in the EEG discharge the muscle action potentials restart with the size of those in the flexor groups reduced less than that of those in extensor groups.

their extreme simplicity and brevity, and the apparent absence of after-discharge. The method of recording used might possibly introduce as an artefact an apparent lengthening of the potential differences; it is highly unlikely to shorten their apparent duration. The recorded action potentials have neither more phases nor greater duration than those evoked by eliciting a reflex jerk with a tendon tap. It does not seem to be possible to produce anything as brief as this by voluntary movements of even the shortest duration. This seems to indicate some highly synchronized form of centrifugal discharge in the myoclonic state. After this stage of the seizure, characterized by the intermittent episodes of jerking, has been in progress for about one or one-and-a-half hours one of the jerks passes, with a pause of usually not more than 2 or 3 seconds, into the tonic stage of a major tonic-clonic convulsion (Fig. 7). It is notable that although the tonic stage of the seizure is well developed by the end of the second part of the record, which is continuous with the first part, there is only a low voltage fast discharge in the EEG and the rate of this, 45 to 50 c/s, suggests that it is of muscular rather than cerebral origin. The absence of the 20 to 25 c/s discharges usually associated with the start of a Grand Mal seizure (Gibbs, Gibbs and Lennox, 1937) has been noted on several occasions in these subjects.

EFFECTS OF SENSORY STIMULATION.—In the period of prodromal muscular jerkings before the major seizure two stages may be distinguished clinically.

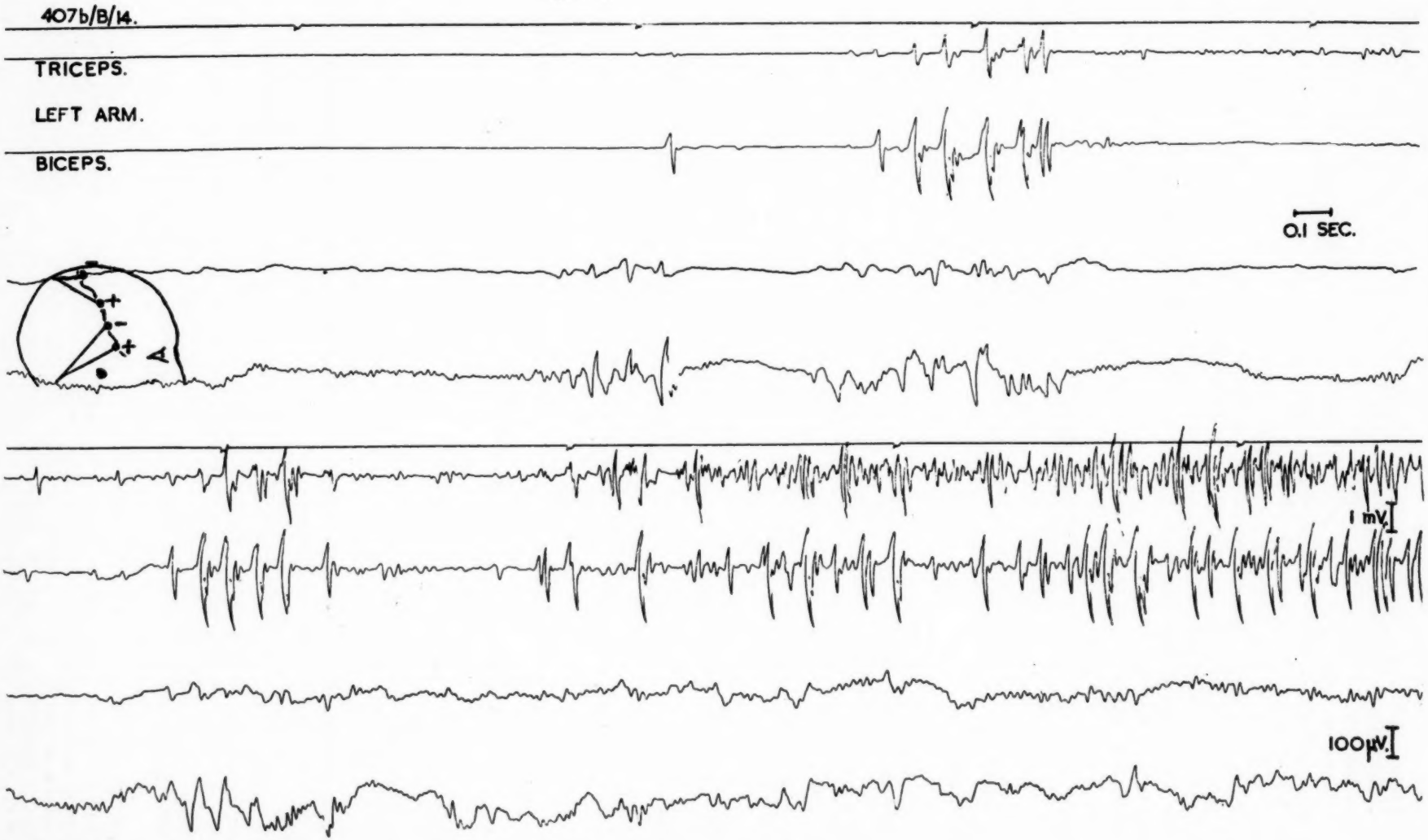

FIG. 7.—The records show a spontaneous myoclonic jerk passing into the tonic stage of a major tonic-clonic seizure. The two parts of the record are continuous and show an absence in the EEG of any high voltage 20 to 30 c/s discharge even in the second part of the record where the muscle discharge is well developed.

In the first stage, if a knee jerk is elicited the initial, normal response is followed by another jerk. The interval between the two jerks varies between 80 and 180 msec. and the second jerk is usually confined to the muscles stimulated, but may occasionally occur in the antagonists (Fig. 8 (*a*) to (*e*)). In this stage no correlate of the jerk is found in the EEG. The action potentials show that the initial jerk, marked KJ in the records, is simple and brief like that in a normal tendon reflex contraction. The action potential of the secondary jerk, marked by the arrow on the records, has a different character: it is multiphasic, increases in size slowly up to a maximum, then declines slowly and shows a considerable dispersion in time. The record showing the shortest latency for the secondary action potential (Fig. 8 (*d*)) was made on a different day and with different amplification from that showing the longest latency (Fig. 8 (*a*)). The difference in the amplifications used does not account for the difference in the latencies as, although some of the earlier potentials in the secondary discharge in Fig. 8 (*a*) may not be visible on account of the lower amplification used for that record, the discharge reaches its maximum 80 msec. later there than in the record of Fig. 8 (*d*). It does not seem to be possible to correlate the latency or the size of the secondary discharge with the size of the initial jerk action potential. The smaller of the two figures for the latency of the secondary jerk (80 msec.) is significantly less than a normal reaction time; therefore, unless the reaction time is considerably shortened in this condition, it is unlikely that the secondary response is a voluntary one to a stimulus that has assumed a startling nature. The secondary response has many of the characters, in a greatly exaggerated degree, of the rebound that occurs normally at the end of the inhibitory silent period

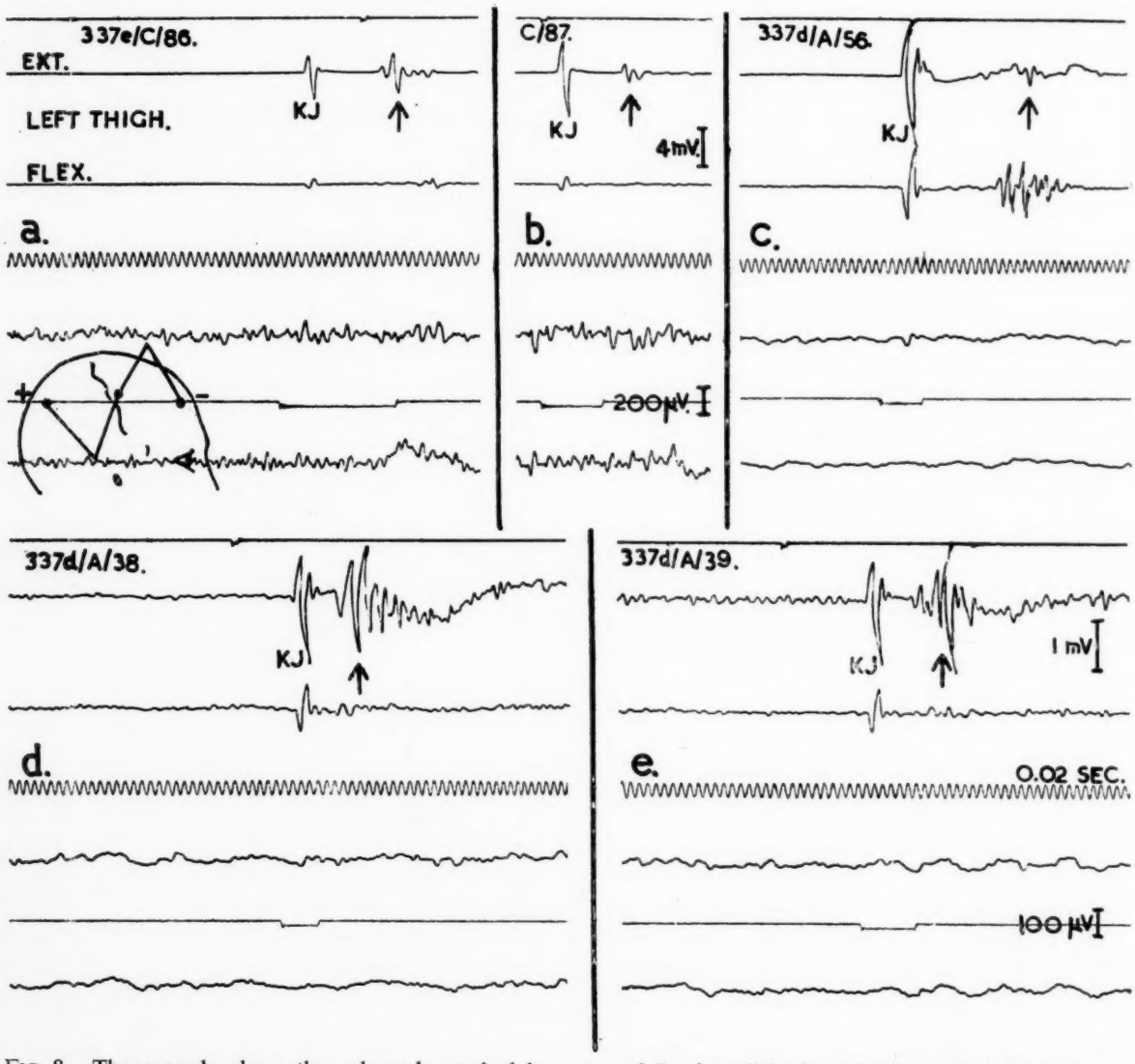

FIG. 8.—The records show the rebound, marked by arrow, following elicitation of a knee jerk, marked KJ, during the periods between spontaneous myoclonic jerkings. No correlate of the secondary discharge in the muscles occurs in the EEG. The signal trace between the EEG records shows that the jerks are evoked, not spontaneous, and does not indicate the exact time of stimulation. Calibrations for (*a*) and (*b*) are on (*b*), and those for (*c*), (*d*), and (*e*) on (*e*).

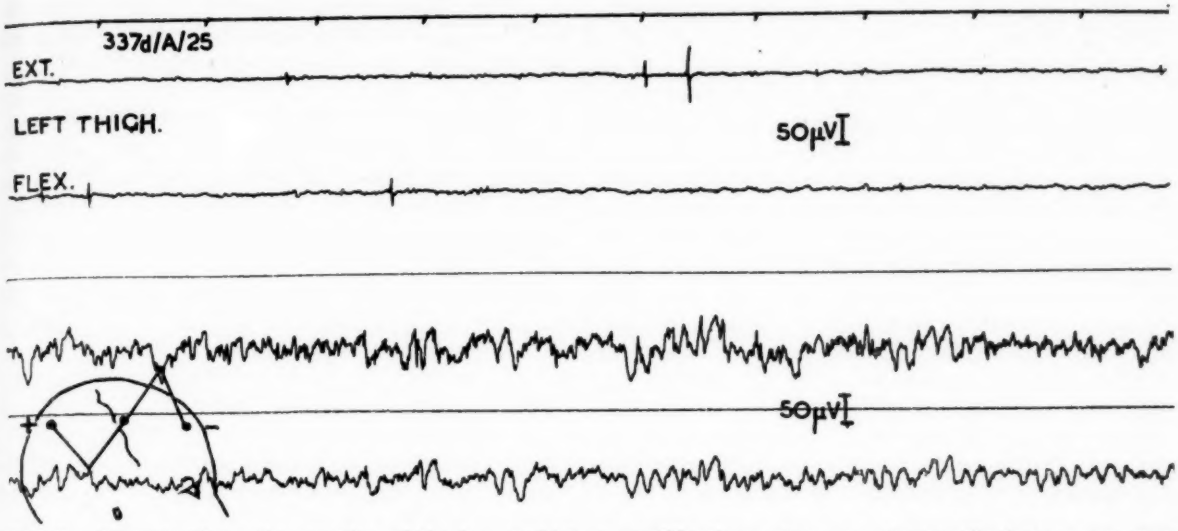

FIG. 9.—Records from the muscles of the leg at higher amplifications show an abnormally large amount of resting fasciculation between the episodes of myoclonic jerking. No correlate of the fasciculation appears in the EEG.

following a tendon reflex. In the normal person the rebound jerk has an action potential that does not exceed one-tenth of that of the primary jerk, whereas in this stage of the myoclonic state it is often as big as, and sometimes greater than, that of the primary jerk. Also in the normal person a large primary jerk is usually associated with a longer period of inhibition than that which follows a small primary jerk.

In the records shown in Fig. 8 a comparatively large potential difference is picked up in the flexor surface electrodes at the time when the extensor action potential of the initial reflex jerk occurs. Some of this potential difference may be due to the direct electrical leakage mentioned in the section on methods. That the major part of the potential difference is not due to leakage is suggested by the absence of any large flexor surface potential during the presence of the secondary extensor jerk potential, even though this is larger than the primary discharge on two of the occasions shown (Fig. 8 (*d*) and (*e*)). If this flexor surface potential difference is arising in flexor muscles, and it seems that this possibility needs to be considered, it must either be excited by the same afferent volley that leads to the extensor discharge, or by the afferent volley excited by the stretching of the flexor muscles at the time the extensor muscles contract. Measurements show a small but relatively constant delay of 5 to 10 msec. between the beginning of the extensor action potential and that of the flexor muscle. This apparent delay is probably not due to any lack of alignment in the oscillographs, errors due to this cause in these records being less than 5 msec. at the recording speed used. This order of delay suggests that the second possibility is the less likely of the two. Without more accurate timing methods it is unwise to draw any conclusions from this finding but, since it is clear that when the myoclonic jerkings occur there is apparently a failure of reciprocal innervation (Figs. 3 and 4), it may be suggested that a similar failure can also occur to some extent in this earlier stage when spinal reflex excitability is increased. That the failure of reciprocal innervation in the myoclonic jerk is not just an artefact produced by electrical leakage of extensor surface potential differences to the flexor surface electrodes is clear, because the flexor surface potential differences commonly appear before those from the extensor aspect of the limb, and also they may increase in size when the extensor potentials are not altering (Fig. 5).

If recordings are made with a high amplification from either flexor or extensor muscles at this stage of the attack an abnormally large amount of resting fasciculation is found (Fig. 9). This fasciculation is irregular and shows no tendency to become organized into bigger jerkings. No correlate of the fasciculation is seen in the EEG. This may possibly be another manifestation of the increased motor neurone excitation shown by the increased reflex excitability and rebound mentioned above.

In the second stage of the prodromal state that may be distinguished clinically, the reflex response to a tendon tap is followed by a generalized myoclonic jerk of the same type as those occurring spontaneously. These jerks may also be provoked by sudden unexpected noises, but a tendon tap seems to be a particularly adequate stimulus. During this stage a clear correlate of the jerk is found in the EEG (Fig. 10 (*a*) to (*c*), which shows the effect of eliciting a triceps jerk in the left arm. The spike potentials that occur in the EEG are the same in general characters as those occurring spontaneously. The delay between the start of the tendon reflex action potential, marked TJ in the record, and the first significant wave in the EEG varies, in the records shown, between 130 and 150 msec.; a similar range of values has been found in other experiments. In the record of Fig. 10 (*c*)

the first jerk elicited was unaccompanied by any cerebral spikes. A spontaneous spike on both sides follows, suggesting a spontaneous rise in excitation, and the next tendon tap is followed by a series of spikes and muscular jerks after an interval of 140 msec. The records of Fig. 10 seem to show that the cerebral discharge starts in larger size on the side of the head contralateral to the limb stimulated than that ipsilateral to it. This result has not been found with sufficient constancy to be accounted significant, but two records taken on the same occasion under the same conditions, when a stimulus has been applied by coincidence after a spontaneous discharge has already begun (Fig. 11 (*a*) and (*b*)), show the cerebral discharge starting in a more nearly symmetrical fashion. This patient on some occasions had a tendency to asymmetry of the discharges and before this may be taken as evidence that the tendon tap evokes a discharge in the contralateral cerebral cortex first, further controls are needed. Both clinically and from the point of view of the EEG this stage is suggestive of the condition of an animal to whose cortex a subconvulsive quantity of a convulsant drug has been applied.

2. Myoclonus with Wave and Spike Discharge

INTERSEIZURE RECORDS.—The subject who has attacks of mild muscular jerkings that last for 24 to 48 hours shows in his EEG between these episodes a main rhythm that varies between 10 and 16 c/s, that is symmetrical on the two sides, largest in occipital leads, and that disappears on opening the eyes. In addition there is low voltage activity at 4 c/s from all parts of the head. Overbreathing produces a paroxysmal discharge at 6 to 8 c/s all over the head, followed by an outburst of waves and spikes of regular form lasting up to 12 seconds. This outburst is accompanied by mild clonic jerkings of all the limbs and a failure to respond to orders.

RECORDS DURING SEIZURES.—At the start of the prolonged periods of jerking the EEG shows a continuous discharge of slow waves and irregular

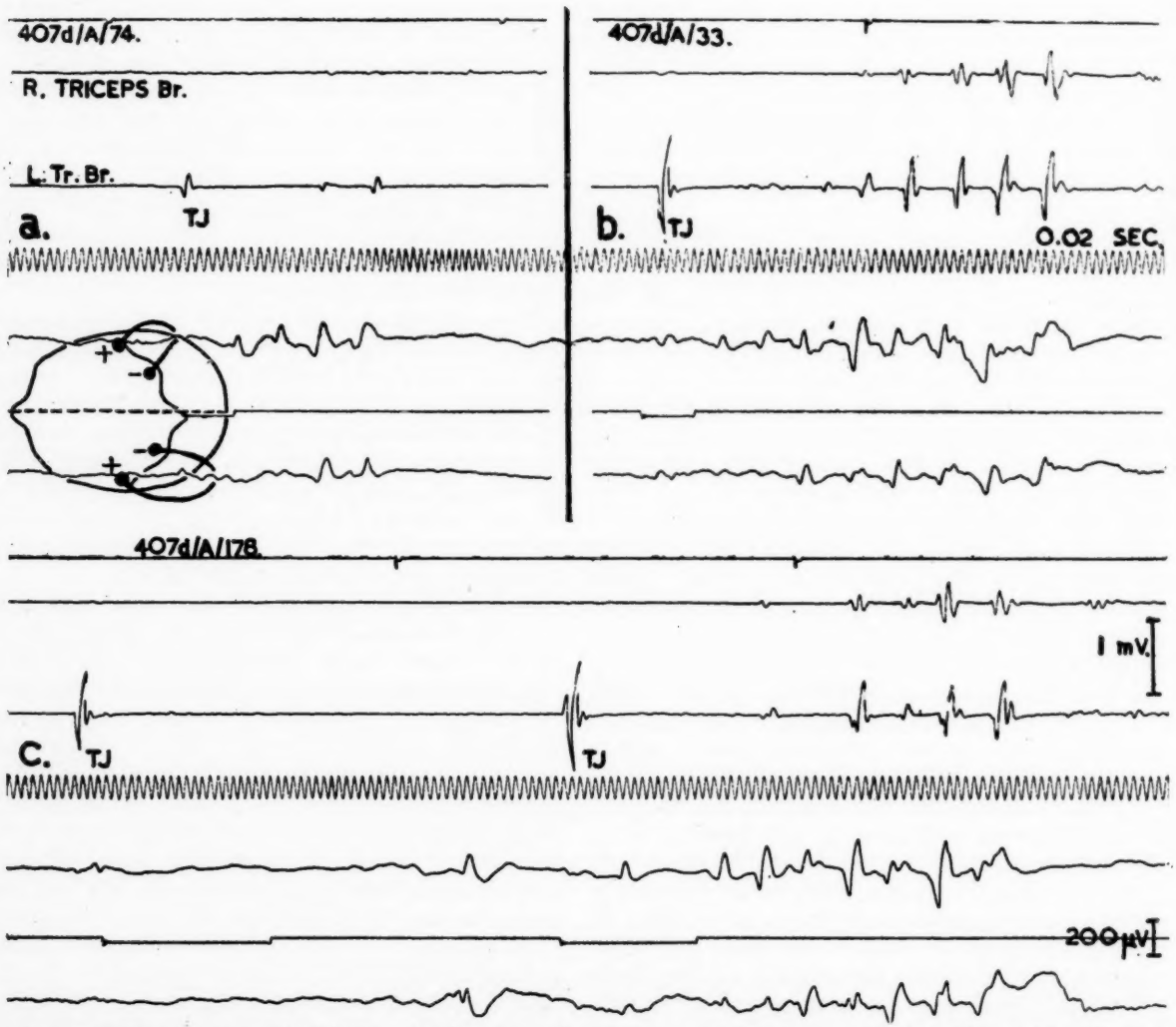

FIG. 10.—Records from the triceps and biceps muscles of the arm to show myoclonic jerkings with spikes in the EEG following the elicitation of a triceps jerk, marked TJ. This occurs at a later stage of the myoclonic state than the effect shown in Fig. 8.

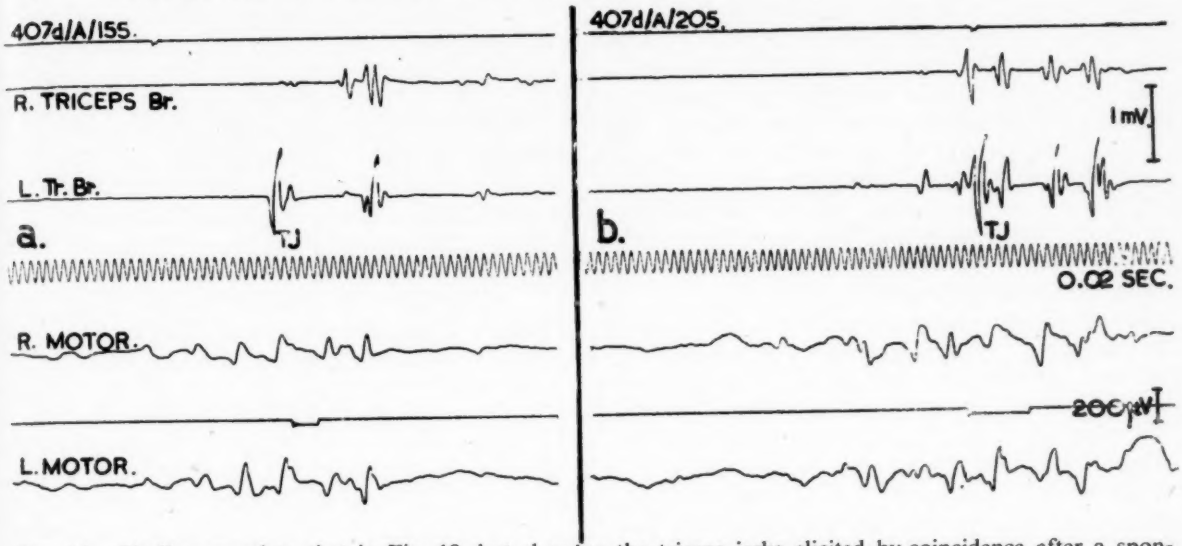

FIG. 11.—Similar record to that in Fig. 10, but showing the triceps jerks elicited by coincidence after a spontaneous jerk has already begun. The EEG record is more symmetrical than in the records of Fig. 10 where the EEG discharge follows the triceps jerk.

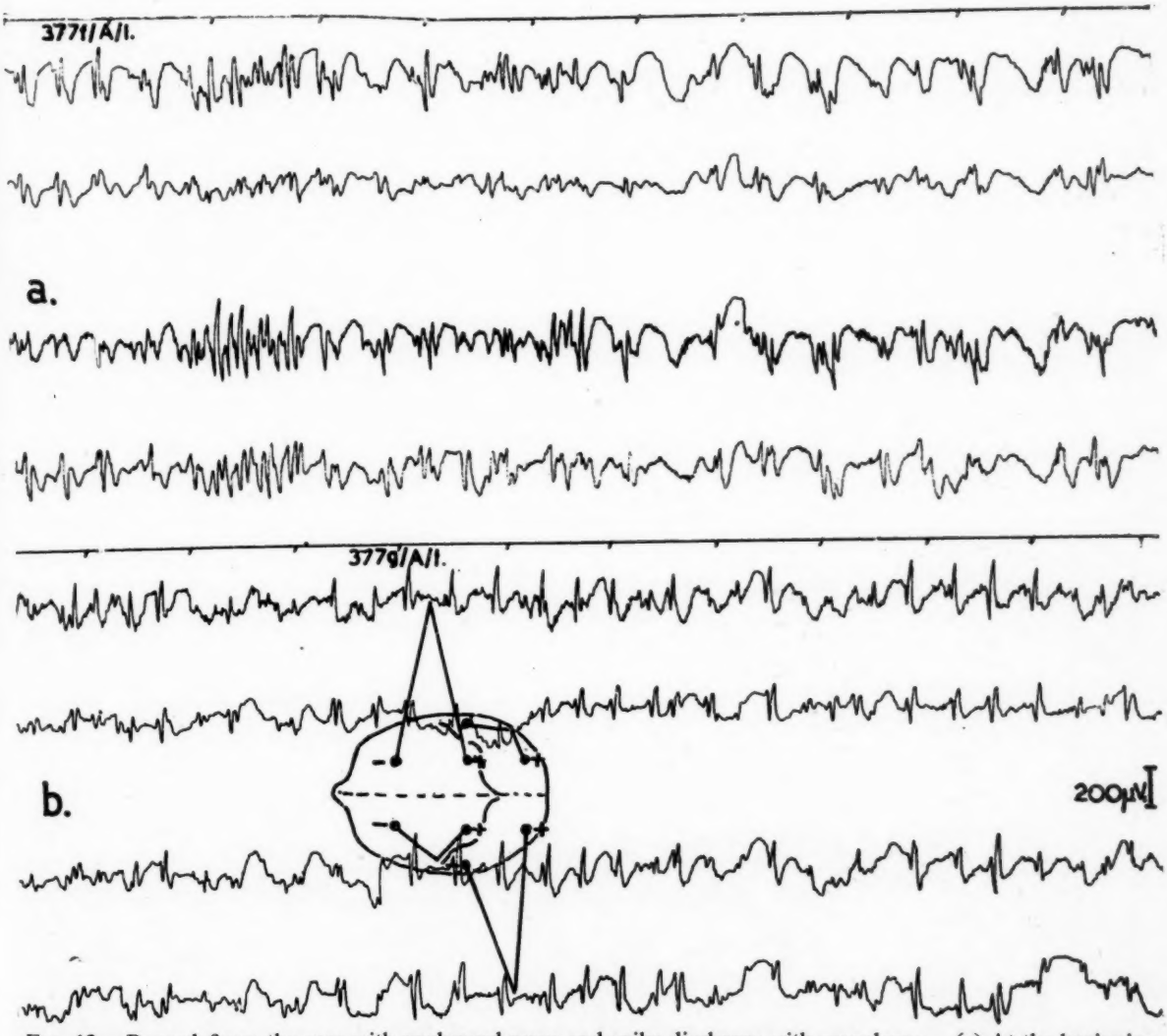

FIG. 12.—Record from the case with prolonged wave and spike discharge with myoclonus. (*a*) At the beginning of the attack. (*b*) Twenty-four hours later when the discharge has become more regular. Calibrations and electrode placements are the same for the two records.

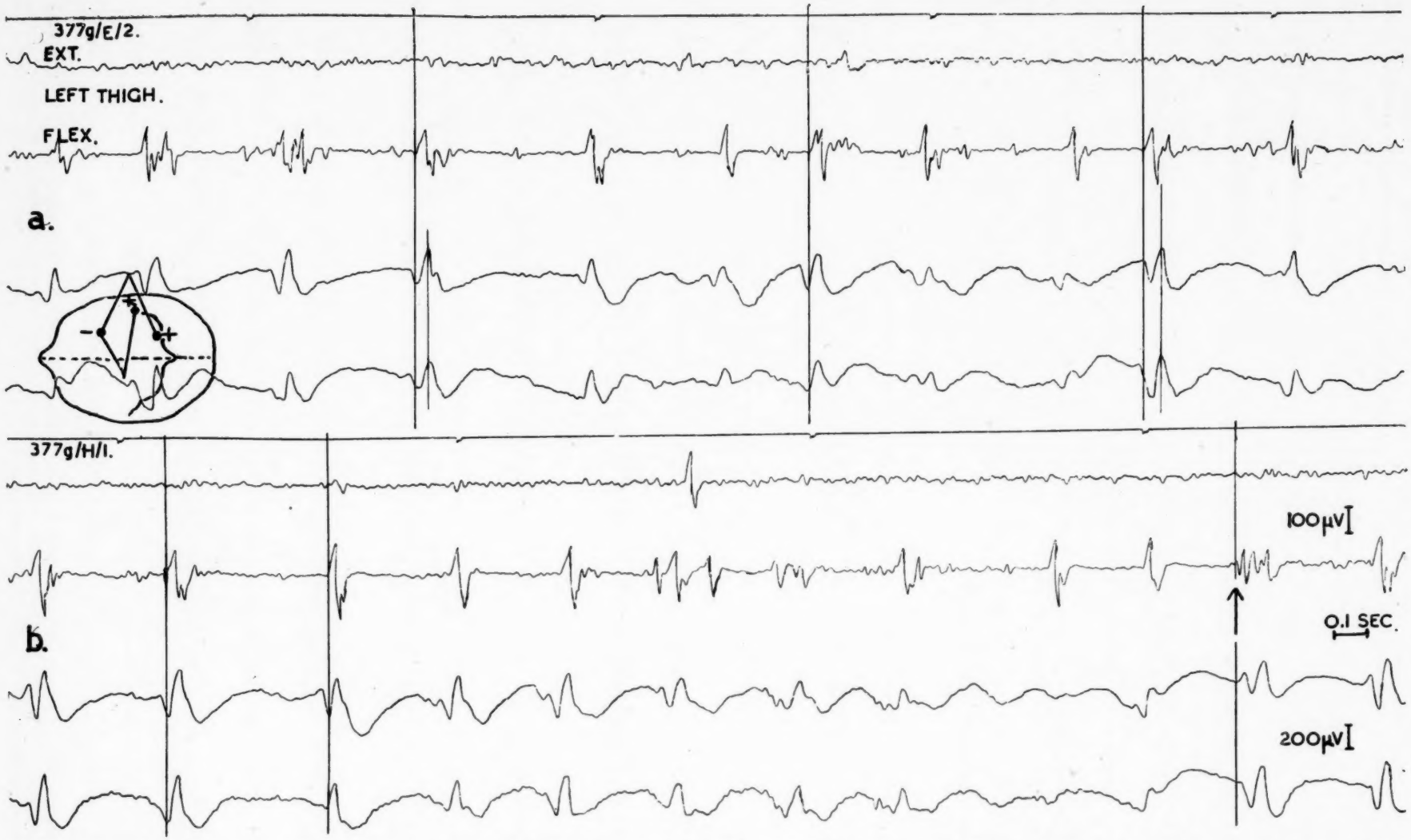

FIG. 13.—Record of muscular jerkings during wave and spike discharge in the EEG. (*a*) shows discharge almost restricted to flexor muscles, and relatively complex form of the muscle action potentials. (*b*) shows a muscle discharge, indicated by arrow, preceding EEG spike, a discharge in extensors following increase by 20 per cent. of spike frequency in the EEG, and a muscle discharge with apparent absence of an EEG spike.

spikes (Fig. 12 (*a*)) over all parts of the head. This stage is characterized by diffuse and irregular muscular twitching in all parts of the body and some clouding of consciousness. After about five or six hours the EEG shows a more regular discharge of wave and spike form (Fig. 12 (*b*)), and the jerking becomes regular and synchronous in different parts of the body. In this stage there is no great reduction in consciousness and, though the subject may be euphoric and frequently whistles tunes, he is able to answer questions intelligently. When this type of discharge has become established it may persist, with little change except some increase in regularity, for 24 hours at 2·5 to 3 c/s, symmetrical on the two sides and with amplitude up to 800 μV.

The muscular jerkings in this condition are clinically very slight compared with those occurring as prodromata of a major seizure, described in the last section. Records of muscle action potentials also show considerable differences between the two types. The discharges in this condition are still brief and may occasionally be as short as those in the myoclonic jerkings, but usually they are longer, have more phases, and an altogether less simple form (Fig. 13 (*a*) and (*b*)). In addition the muscle discharge may remain localized to the flexor muscles, where it first appears, with only occasional discharges in the extensors. The time relations of the EEG spike and the muscle action potential appear to be more variable in this condition than in the more severe myoclonic state. In that state the muscle action potentials have never been found to precede the cortical wave and usually are delayed after it by not less than 15 msec. In the wave and spike seizure the muscle action potential does not seem to be so constantly delayed and may actually precede the earliest recognizable phase of the EEG spike (Fig. 13 (*b*) at the point marked by the arrow.) This suggests that in the wave and spike seizure the efferent discharge giving rise to the muscular activity is not a direct correlate of the EEG spike, but that both are manifestations of some process that reaches its peak at the time they occur. That the presence of a detectable cortical spike is not necessary for the occurrence of a muscle discharge in the wave and spike seizure is also suggested by the later part of the record in Fig. 13 (*b*). In this case it cannot be ruled out, however, that the apparent absence of the cortical spike may be due to the electrode arrangement used, and a movement of the area of greatest cortical activity with respect to the electrodes; this is suggested by the slow decline and return of the EEG spike at that part of the record.

The difference in size of these muscle action potentials when compared with those in the myoclonic prodrome is striking. In the latter state, with the electrode arrangements used, the potential differences may be as much as 10 mV. Under the same recording conditions the potentials during the wave and spike seizure rarely exceed 200 μV. The size of the spikes in the EEG is similar to that in the myoclonic prodrome, their duration is of the same order, and the same areas of cortex are discharging abnormally. Some other factor than these must therefore be sought to account for the small size of the muscle discharges in this wave and spike seizure, and their absence or even smaller size, in most seizures of this type. It may be that one factor is the longer interval between the efferent discharges in the wave and spike seizure. Since these discharges seem to reach their peak at about the time the spike occurs in the EEG they do not approach within less than about 0·3 of a second of one another. In the myoclonic prodrome it was seen that during such a period some decay will occur of the facilitation associated with a preceding spike or spikes. Spikes appearing at a rate of three per second, and not preceded by a burst at a faster rate, may not be associated with the building up of sufficient excitatory state to cause a larger discharge in the muscles. That this factor may possibly be an important one is suggested by the

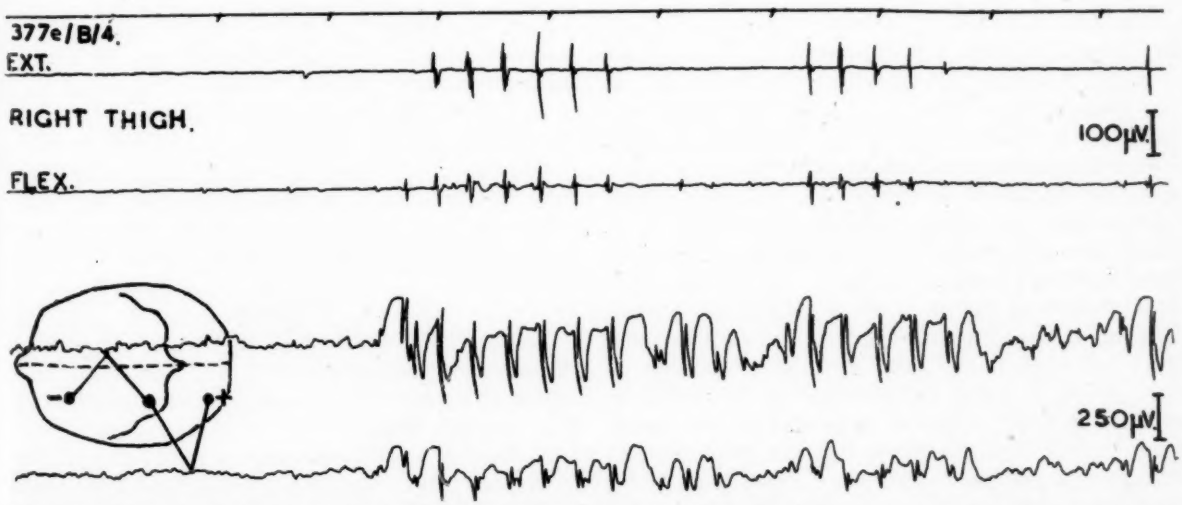

FIG. 14.—Record of the muscular jerkings accompanying wave and spike discharge evoked by overbreathing. Compare the small size of the muscle action potentials with those in the severe myoclonic jerkings (Fig. 4 (*a*)). The small deflections in the flexor record before and after the seizure are an artefact due to the electrocardiogram.

record shown in Fig. 13 (*b*). Here the sole discharge in the extensors takes place after three waves and spikes have occurred with an interval between them 20 per cent. shorter than that between those preceding them. Thus the differences in the two conditions may be due solely to the different amounts of facilitation occurring, and it is not necessary to postulate that the efferent cerebral discharges in them are different in either nature or magnitude.

In the periods following spontaneous seizures, overbreathing may sometimes evoke wave and spike discharges. In the later parts of the interseizure period these evoked outbursts are associated with muscular jerkings similar to those occurring in the spontaneous attacks, and the muscle action potentials are synchronous with the spikes in the EEG (Fig. 14), and here as in the myoclonic prodrome the discharge begins in the flexor muscles. In the earlier part of the interseizure period the number of wave and spike complexes evoked by a given amount of overbreathing is less than at a later time. Often only a single wave and spike or slow wave occurs (Fig. 15 (*a*)) and no muscle discharge is seen. If the muscle or group of muscles being tested is now stretched slightly it is often possible to pick up a simple rhythmic discharge from what is apparently a single motor unit. Under these conditions when a single wave and spike or slow wave occurs in the EEG the rhythm of the single unit is interrupted and a discharge is interpolated (Fig. 15 (*b*) and (*c*)). In the latter part of the figure it seems that the rhythm is " reset " from the point where the interpolated discharge occurs. In this case the delay between the wave in the EEG and the muscle discharge is longer and less constant than it is when the regular repetitive spikes occur in the EEG. Probably the delay depends on the level of excitation at the motor neurone level at the time the efferent cerebral discharge reaches it.

Discussion

The results of the investigations described above in the patients with severe myoclonic jerkings confirm the findings of Grinker *et al.* (1938), and in the patient with wave and spike discharge with myoclonus those of Jasper and Andrews, (1938). The present cases of severe myoclonic jerkings show spikelike discharges in the EEG apparently exactly comparable with those described by Grinker *et al.* After discussing their findings Grinker *et al.* decided that the disturbances in myoclonic epilepsy probably had a cortical rather than a subcortical origin. The evidence available from the present studies does not make it profitable to speculate further on this point, for the disturbances in the EEG in myoclonic epilepsy are so large and so widespread that it seems highly unlikely that of cortex or basal structures, pyramidal or other efferent systems, any one will be active in isolation. In spite of the probable diffuse nature of the disturbances during the seizure there are indications for further study. There are clearly changes in the tendon reflexes which indicate an increase in spinal excitability, at any rate for extensor reflex mechanisms. Since these changes are unaccompanied by any obvious changes in the EEG, some steadily maintained discharge affecting the spinal centres, or the removal of such a discharge, must be of importance in the periods between jerkings preceding the major convulsion. How far these changes in spinal excitability determine the pattern of the jerkings when these do occur is not clear, though it is obvious that the part played by them is considerable. The greater accessibility of the flexor mechanisms to the abnormal discharges in the two cases described, shown by the muscle action potentials, may be taken to suggest that although the pyramidal system is almost certainly not the only one discharging abnormally in these cases, it has the dominating influence at the spinal level.

It must be emphasized that the finding that muscular jerkings accompany spike discharges in the EEG does not apply to all types of myoclonic epilepsy. Many of the minor myoclonic phenomena that occur so frequently in epilepsy (Russell Reynolds (1861) has estimated that 75 per cent. of all epileptics have them in some form) seem to show no correlates in the EEG. One subject at The David Lewis Colony showed a rhythmic twitching of the face, arm, and leg of one side of the body only, which could not be associated with any disturbance in the EEG. Unfortunately the jerkings in this patient ceased before full investigations could be made.

The findings in the patient with wave and spike discharge with mild mycolonus show a rather closer correlation of the spike of the complex with the burst of muscle action potentials than in similar cases described by Jasper. Like his cases, this patient also shows that the spike of the cerebral discharge and the muscle discharge may not be directly related but are probably both correlates of some third process. It seems that the presence of efferent cerebral discharges, in themselves subliminal for excitation at the spinal level, may be inferred from their effects on a purely spinal reflex mechanism, such as the rhythmic discharge of a stretched single motor unit. This suggests that if studies are carried out at the spinal reflex level, in conditions other than epilepsy, a closer correlation may be found between cerebral rhythms and peripheral effects than has so far been shown by studies at the lower level of the muscles themselves.

Summary

1. The EEGs of two subjects with severe myoclonic seizures and one subject with mild myoclonic jerkings accompanying wave and spike discharge in the EEG are described.

2. Repeated simultaneous recordings of the EEGs and muscle action potentials have been made in these subjects during myoclonic episodes.

3. All subjects show some form of spike discharge, with or without a slow wave, in the

FIG. 15.—Records of single wave and spike or slow wave discharges in the EEG (*a*) unassociated with muscle discharge, (*b*) and (*c*) associated with interruption of rhythm of single motor unit discharge which has been evoked by stretching the muscles.

inter-seizure periods. In the seizures the patients with the severe myoclonic jerkings show discharges of spikes in their EEGs with a period of 30 to 75 msec. at a rate of 8 to 13 per second.

4. There is an accurate correlation between the occurrence of the spikelike discharges in the EEG and the action potentials of the muscular jerkings in the severe cases and a less accurate correspondence in the mild case.

5. The muscle action potentials show recruitment and facilitation having a different time course of decay for flexor and extensor muscles.

6. In the periods between the spontaneous jerkings changes in spinal reflex excitability may be demonstrated.

7. Important differences in the characters of the muscular jerkings in the severe myoclonic states and the milder state accompanying wave and spike discharge are described.

8. These findings are discussed and their bearing on the origin and mediation of the abnormal discharges in these conditions are considered.

The author would like to express his thanks to the Committee of The David Lewis Colony who made this work possible, to the Medical Research Council for facilities to complete it, and to Dr. Handley, Director of the Colony, for his advice and constant encouragement.

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THE DISORGANIZATION OF BEHAVIOUR IN FATIGUE

BY

D. RUSSELL DAVIS

From the Medical Research Council Unit of Applied Psychology, Cambridge

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MANY studies of mental fatigue have been governed by the expectation that its effects were to be found in a decline in the quantity or quality of the output, and tests have been employed in them involving the repetition of elementary operations. Bartlett (1943) contended, however, that effects related to real life were to be found in the disorganization of skilled activities, of which the work of every-day life largely consists. He therefore proposed that the organization of a relatively complex skill should be studied under conditions which might reasonably be assumed to be fatiguing. This was made possible by an ingenious apparatus, now called the Cambridge Cockpit, which was designed and built by the late Dr. K. J. W. Craik. Bartlett has described some of the results of the first experiments with this apparatus, which were carried out by Drew, and has shown how they throw light on the organizing functions of the central nervous system. He has referred mainly to the perceptual aspects of the disorganization. This paper, based upon further experiments by the author, amplifies Bartlett's account in several respects and deals mainly with the motor aspects.

Method and Procedure

The Cambridge Cockpit was like a Link trainer, used for the teaching and practice of instrument flying. It was operated, however, by a different system from that of the Link trainer and had several advantages over it for the present experimental purpose, particularly because the movements of the controls and the resulting movements of the instruments could be recorded graphically in a form which could be readily scored. The cockpit itself did not move, although the instruments responded realistically to the movements of the controls. Their effects were less complex than those of an aircraft, however, since only the primary effects were produced, but, in spite of this and other differences from an aircraft, the test was accepted as a reasonable one by all the experimental subjects, and the similarity to flying was an important factor in their motivation. On the other hand, elaborateness of the apparatus limited its applicability, and it was, in general, too specialized for any but aircrew subjects. The subjects of the experiments to be described were R.A.F. pilots, fit for flying duties at the time of the test. The subjects carried out an exercise in instrument flying, which was of the same form in all the experiments. A series of four manœuvres, together occupying ten minutes, was repeated between intervals of straight and level flying. Only the periods of the manœuvres were scored, and the scores of successive periods were compared with one another.

The records of the "side-slip" instrument proved to be of particular interest, and this instrument was recorded in all the experiments. The directional gyroscope, airspeed indicator and altimeter were recorded in some experiments. The instructions and the recording were so arranged that the perfect performance was recorded as a straight line, unaffected by errors of timing of the manœuvres. Three types of score were obtained from the records of the instruments and were measures of errors in the control of the machine. The number of deviations of an instrument reading, exceeding an arbitrary minimum divergence from the prescribed reading, was counted, and since the deviations had always to be terminated by action on the part of the subject, this number was called the "corrections" score. The total time for which an instrument showed a similar deviation was measured with a map-measurer and tamplet and was called the "total duration of errors." This score was divided by the "corrections" score to give as the quotient a third score, the "average duration of errors." Counters of a cyclometer type were attached to each of the controls and measured the total amount of movement. This score is referred to as the "movements" score. Graphic records were made of the elevator and aileron movements whenever it appeared useful to do so.

Various other observations, including the timing of manœuvres, were made systematically. In particular, a note was made if the subject forgot to reset the "fuel contents" indicator, an action which was necessary every ten minutes. The resetting of this indicator was an example of the several actions which had to be performed only occasionally and were liable to be forgotten. Various ratings were made systematically on the basis of impressions gained at the beginning, during the course or at the end of the test, and subjects were questioned carefully at the end of the test. The test was assumed to be fatiguing, the important factor in producing fatigue being regarded as the difficulty subjects encountered in attaining a standard of performance satisfying to themselves. They strove to attain a standard of accuracy which was at least partly derived from their flying experience, but because of the characteristics of the apparatus it was difficult to attain the standard required when flying an aircraft. In any event, subjects, whether pilots or not, were liable to fall short of the standard which they set themselves, however it may have been derived. Thus, their efforts to attain a satisfying standard were frustrated, and they suffered the experience of failure. In this situation they were obliged to perform a skilled task for a relatively long time.

Results

Drew (1941) tested a large group of pilots and found that "side-slip" scores increased considerably as the test continued. He worked mainly with a single score from each instrument, which was roughly equivalent to the product of the scores of "corrections" and "total duration of errors." The curve drawn from the means for successive ten minute periods of a two-hour test had a somewhat unexpected shape, since its gradient was at first positively accelerating and then became negatively accelerating. This result suggested that there were two phases of the effects of the test conditions. Moreover, at the part of the curve at which the gradient changed, the scatter of the scores increased considerably, and this fact suggested that there were

considerable individual differences in the time of development of the second phase. Further evidence was sought on these points.

I. Thirty-four relatively inexperienced pilots carried out a two-hour test. Four periods of the test were compared with one another, each being of twenty minutes and comprising two series of manœuvres. Means were calculated from the sums of the scores of the individuals. In general, they had a rather high standard deviation, but the trends described below were significant on the statistical

Three other observations were considered to be of importance. It was seen from the graphic records that after the second period the aileron movements became few and large instead of many and small, as they had been, although the counter score remained the same. The errors in the instrument readings increased in size towards the end of the test, as Drew had also found, and there were few large errors in place of many small ones. Thirdly, the number of omissions in resetting the "fuel contents" indicator fell from the first to the third period, but

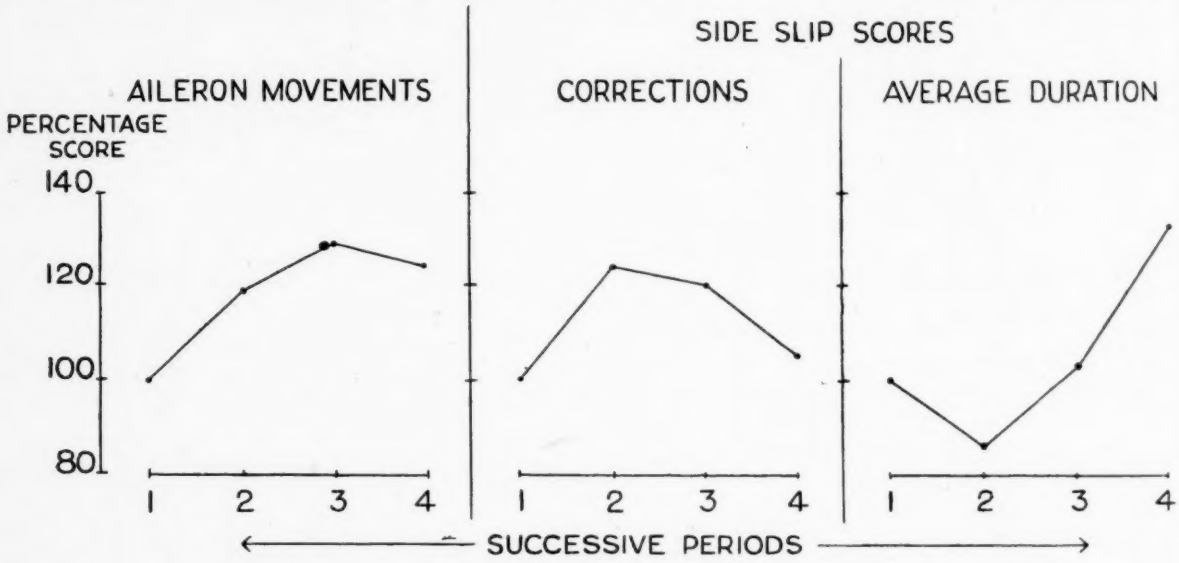

Fig. 1 Fig. 2 Fig. 3

FIGS. 1, 2 and 3.—The trends in the numerical scores in a two-hour test.

criterion that the "probability" was less than 0·05.

It was found that the deterioration during the first part of the test affected control similarly in the three planes of movement, but towards the end of the test the "rolling plane" (side-slip) was the most affected. It was unlikely that this adverse effect on the "rolling plane" had any practical importance, but, as will be seen later, its selection was an artefact of the instructions. Aileron and side-slip scores were chosen for special study, and the means of these scores are displayed in Figs. 1–3.

The aileron "movements" score increased from the first to the second period, after which it did not alter significantly. The "corrections" score of the side-slip increased to a peak at the second period and fell to just above the initial level from the third to the fourth period. In contrast, the "average duration of errors" did not increase significantly above the initial level until it rose steeply from the third to the fourth period. The air-speed scores showed similar trends, but the trends were less marked and were not significant statistically. The "corrections" score of the directional gyroscope showed the same trend as that of the side-slip, although the peak at the third period was later. It fell significantly in the fourth period. The "average duration of errors" showed a different trend, however, since it decreased with each successive period.

then increased significantly.

These results were considered to indicate two phases of the effects of the test conditions, which it is proposed to refer to provisionally as the phase of "overactivity" and the phase of "withdrawal." The first phase of "overactivity" was transient and corresponded to the increases in the number of control movements and the number of corrections. The second phase, "withdrawal," corresponded to the decline in "corrections," to the increase of the "average duration" and size of errors and to the increase of omissions of the resetting of the "fuel contents" indicator. It appeared that in the first phase all aspects were affected, but the second phase affected only the "rolling plane" and the occasional actions.

Less systematic observations and the subjects' reports also pointed to two different phases. In the first part of the test, subjects felt tense, under strain or irritable and, sometimes, frankly anxious. Corrections were made with impatience and were hurried, and subjects felt that correction was urgent. They were often preoccupied with one or other aspect of the task which had acquired a temporary urgency. Their attention was "sticky" and was held by one aspect, instead of being distributed over the whole field of events. They were distractible in the sense that recent instructions or interventions gained the greater part of their attention. They tended to sit more erect and to grasp the controls more firmly.

The task seemed more difficult, and this was sometimes felt to be unreasonable and was blamed on the working of the machine, while it was actually due to the change in the nature of the movements which the subjects made. Such sources of irritation and physical discomfort tended to gain their attention. Towards the end of the test they tended to relax, concentration failed and interest declined. The feeling of strain gave way to one of mild boredom, tedium or tiredness; sometimes, however, they felt satisfied with a standard of accuracy which was lower than when they were fresh. The task might appear easier because part of it was being neglected or, in other cases, because certain errors were accepted as inevitable faults of the machine and not as the responsibility of the subject. However, many retained a sense of dissatisfaction, but were no longer distressed by it and were more aware of tiredness and discomfort.

Some aspects of the task were better preserved than others, and this was shown in other experiments to depend upon the importance laid by the subject upon the several aspects. The more important an aspect was thought to be, the better it was preserved. On the other hand, control of the " sideslip " was particularly affected, because its importance was given less weight in the test instructions than other instruments. Side instruments, such as the " fuel contents "indicator, were neglected more than the central ones. Thoughts began to wander and careless mistakes were made. Manœuvres were omitted or carried out in the wrong order. Subjects might remark that their reactions had become slower, but it was possible that the delay occurred in the noticing, or appreciating, that an instrument needle had deviated, for the correction itself was often, although not always, brisk. Extraneous signals were variable in their effects.

The effects differed from one individual to another. In some cases there was a clear-cut transition from the first to the second phase. In others, there was a blend of the features of the two phases, a tendency to make larger and less appropriate control movements being reinforced by inattentiveness and, thence, by the larger size of errors before they were corrected. Indeed, quite a marked degree of inattentiveness might co-exist with excessive activity and irritability. Some subjects showed slight or no effects even at the end of the test. In some, the first phase was intense and prolonged, whereas in others it was slight and passed quickly. It was certain, however, that unless there was a change in the experimental conditions, an increase in the average duration and size of errors, an effect characteristic of the second phase was not followed by an increase in the activity.

II. The two phases were regarded as distinct reactions to the test conditions, the trends revealed by the group scores representing the two successive reactions of the average subject. Individual differences were relatively large and, since two reactions appeared to be involved, it was thought to be more satisfactory to separate individuals into two classes, according to which reaction was the predominant one, than to study the average trends of a heterogeneous group. Such a separation was made, therefore, a third class being added of those who showed little or no effects. This classification provided the opportunity of a closer linking of mental experience with behaviour.

In order to facilitate the classification of individuals, a test of 46 minutes was standardized, the whole session with instructions and practice occupying 70 minutes. For purposes of scoring, it comprised four similar periods of ten minutes. It was then applied to a large number of subjects, the main group comprising 355 fit pilots, all of whom had had more than 200 hours experience of flying. The mean scores were found to show the same trends as were shown in the first experiment, although the effects at the end of the test were less advanced by reason of the pilots' longer flying experience.

The subjects were classified on criteria which were based on their scores. About three-quarters (268), who showed slight or no changes, were put into the " normal " class. The remainder were then divided into " overactivity " (59) and " withdrawal " (28) classes on the criterion of the ratio of the " total duration of errors " to the " movements " scores of the fourth period. In the case of all the criteria the distribution of scores was a continuous one with a single mode, and the nearer one approached to the arbitrary line of division, the greater was the number of subjects. Nevertheless, the range of variation was considerable, as Fig. 4 and Table I show. By this method of classifying individuals a more detailed picture was obtained of the characteristics of the two phases, or reactions of " overactivity " and " withdrawal."

TABLE I

Class	Test period			
	First	Second	Third	Fourth
" Normal " (A) ..	16	68	42	75
" Overactivity " (B) ..	80	295	270	509
" Withdrawal " (C) ..	60	169	52	18

" Movements " scores (elevator) of representatives of the three test classes.

The " Overactivity " Reaction.—The increase of activity was at first intermittent. It was the more frequent the greater the demands on the subject, as, for example, when he was required to carry out two or more manœuvres separated by only a short interval of " straight and level " flying. The tendency to excessive movement appeared to be related also to the irregular distribution of attention from one aspect of the task to another. The periods of excessive activity became gradually more frequent and lasted longer as the test progressed. Fig. 5 shows typical examples of the changes in the movements of the controls. At the beginning of the test, the movements were of small range and there was

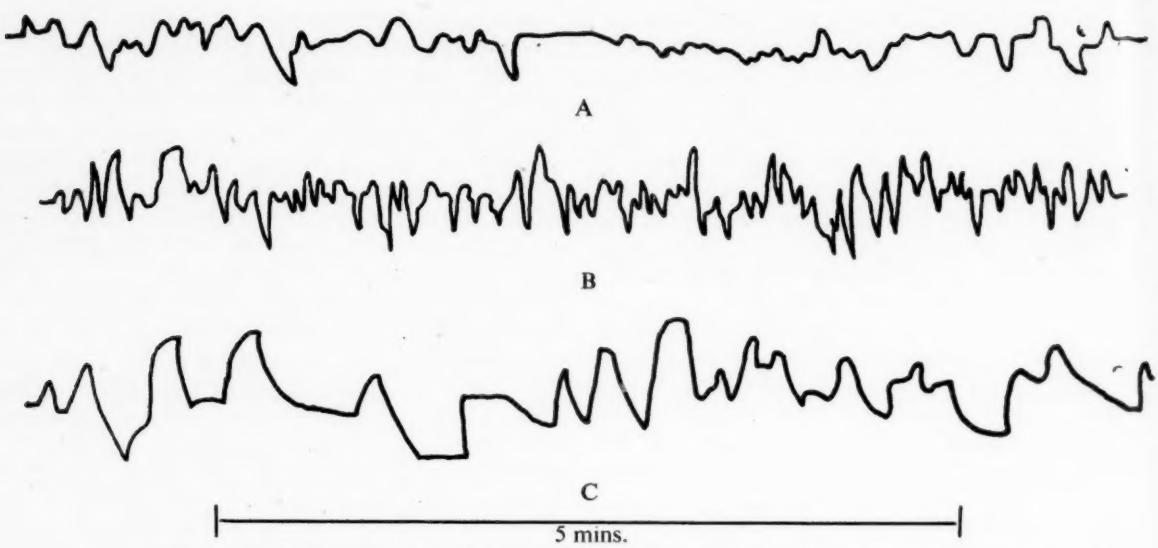

FIG. 4.—Extracts of the side-slip records of representatives of the three test classes.
A. " Normal " class.
B. " Overactivity " class.
C. " Withdrawal " class.

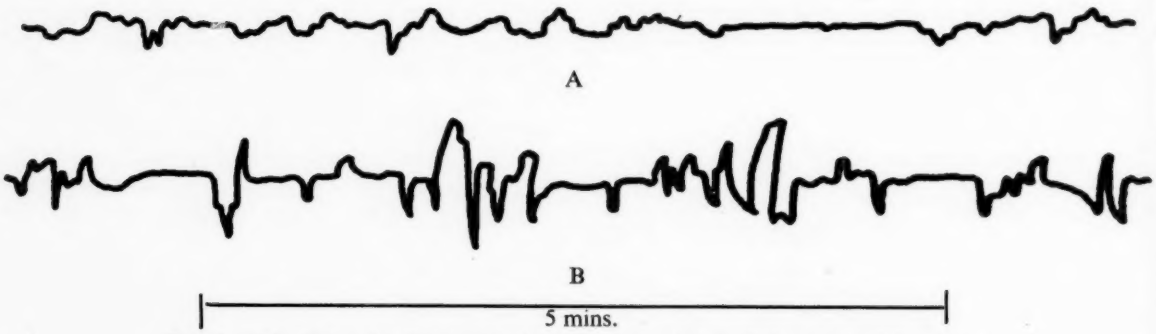

FIG. 5.—The " elevator " movements of a representative of the overactivity class.
A. At the beginning of the test.
B. 30 minutes after the start.

a ripple of small adjustments. At a later stage, the ripple had gone from the stretches of steady flying, and the record was interrupted by large, irregular movements. The principal changes appeared to be an increase in the extent and gradient of the individual responses to deviations of instrument readings, an increase in overcorrecting and, hence, in secondary responses, and an increase of restless movements of small range.

These other features were typically shown by subjects in the " over-activity " class: (i) *Persistence*. Their reports indicated that they continued to try to overcome the difficulties of the test. They were dissatisfied with their performance, but were not discouraged and were determined to improve it. (ii) *Emotional disturbance*. They experienced emotion, and signs of emotional disturbance, such as agitation and restlessness, were observed. They felt excited and, as has been stated, tense and under strain. Irritability was common. In some cases subjects reproached themselves, but in others irritability was directed at the machine or at the conditions of the test. It was often frankly aggressive, subjects admitting the intention to injure the machine, but usually denying that the intention was expressed in action. Only a few subjects admitted to such expression, and, even in these cases, it has to be supposed that such actions were restrained to a varying degree or were insufficiently organized to be effective, since actual damage to the machine was rare from this cause. In other cases, however, random and unorganized control movements reached such a size and force that the mechanism was endangered. Violent manipulation of the fuel cock was the most common form of expression, and some subjects thumped violently on the instrument panel, complaining that an instrument was acting wrongly. Others swore vividly. (iii) *Preoccupation* with the test. Reports were obtained from many of these subjects that they had been preoccupied with the test after it was finished. Sometimes a subject returned later in the day to ask for a further opportunity of doing it or talked about it with surprising persistence. In several cases, when it was possible to obtain reports, it was related that thoughts about the test had recurred compulsively before going to sleep on the evening of the test. (iv) *Flushing of*

the face. No special measures of recording bodily changes were employed, but coarse changes of various kinds were observed and rated. Thus, erectness of posture was observed and was typical of the "overactivity" class. There emerged one other striking difference between the classes. Flushing of the face was observed at the end of the test in 61 per cent. (36 subjects) of the "overactivity" class, whereas the proportion in the "normal" and "withdrawal" classes were 37 per cent. (99) and 11 per cent. (3) respectively. Visible sweating occurred in several of the "overactivity" class. Pallor was observed occasionally, but did not appear to be characteristic of either reaction. (v) *Cumulative effects.* Repeat tests were applied to some subjects at intervals of one or two days. The performance usually improved with each successive test, but, in some cases, where activity was excessive this class contained less than 10 per cent. of the whole group, the associated features were less definite and less constant than in the case of the "overactivity" class, and it is probable that the score changes were the common result of more than one psychological process.

In contrast to the restless striving of the "overactivity" class, the subjects of the "withdrawal" class gave the impression that they had lowered their standards of performance to a level well within their powers, and that there was no gap of relative failure between their attainment and aspiration. Errors, previously felt as threatening to their success, were not corrected and did not disturb them emotionally, and their judgment of the degree of accuracy to which they had attained was often faulty. They were not aware that they had left errors uncorrected and tended to be satisfied with their performance.

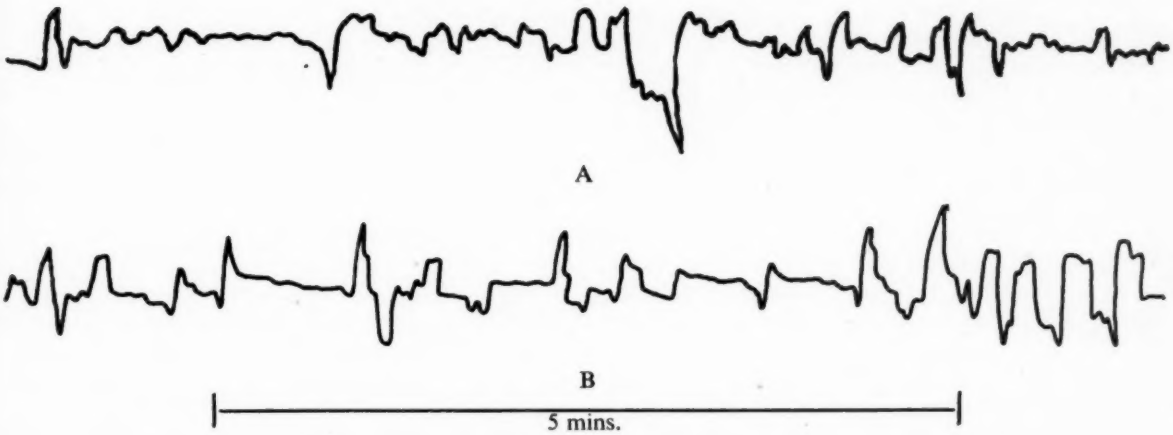

FIG. 6.—The "elevator" movements of a representative of the withdrawal class.
A. At the beginning of the test.
B. 30 minutes after the start.

in the first test, the increase of activity was more rapid in the later tests than during the first. This fact showed that the effects of the test conditions might be progressive from test to test, in the same way as they were progressive in the course of a single test.

The "Withdrawal" Reaction.—A definite increase in activity was observed in the majority of cases before the increase in the size and duration of the errors, characteristic of the "withdrawal" reaction, but the reaction developed early by comparison with the first experiment, because of the method of selecting the subjects for study.

The increase in the extent of the responses, characteristic of the "overactivity" reaction, persisted at first, while the instrument deviations became larger and lasted longer, but the responses were less hurried and less disturbed by restless movement, as Fig. 6 shows. While in some cases activity, as measured by the "movements" scores, declined to a very low level, generally the responses remained more extensive than at the beginning of the test, this change being related to the larger size of the deviations when they were corrected. Although They admitted that they had become bored and had indulged in day-dreaming. It is probable that these effects were like those described in previous experiments on mental fatigue, in which a decline of output or loss of accuracy had been observed, complicated, in the way which Bartlett has discussed, by the greater complexity of the sensory pattern. As in these experiments, the effects were temporarily reversed by changes in the experimental conditions. Such changes revived the subjects' interest, although any improvement was short-lived.

Other subjects reported a loss of interest, but in a different setting. They were more aware of the deficiencies of their performance and were dissatisfied with it, but did not seem so distressed as those in the "overactivity" class. Several of them were observed to be tense in posture and to be restless. Some blamed their inaccuracy on the apparatus or the conditions of the test. Blaming the apparatus or the test conditions was in the nature of an excuse and was not associated with the emotional disturbance characteristic of the "overactivity" reaction. The dissatisfaction of these subjects was not translated into effective activity;

they were not provoked to irritability or anger and were apathetic. Their response to the demands of the test was an insufficient one, and they were discouraged.

Discussion

It was assumed *a priori* that the test was fatiguing; that is to say, that the effects observed in the test were of the same kind as those occurring in states of fatigue, particularly in those which arise from the stress of flying. Although it was not the purpose of these experiments to prove this relationship, it may be remarked here that the assumption was compatible with the results obtained. Thus, many of the observed effects were similar to the symptoms reported by pilots in fatigue, e.g. " overcorrecting " and " stickiness " of attention, while flying, restlessness, irritability, preoccupation with flying and disturbance of sleep, on the one hand, and loss of concentration, loss of interest in and keenness for flying, apathy, discouragement, and depression, on the other hand. However, there is little direct evidence to show how skill in flying is affected in fatigue, except that accidents are said to be commoner, so that in this respect no comparison can be made.

The use of the term " fatigue " was provisional, except as a convenient rubric, since fatigue has no precise meaning in psychology and is applied to any of a series of states running all the way from true physiological exhaustion to psychological frustration uncomplicated by any detectable somatic disorder. When the experiments with the Cambridge Cockpit were planned, it was expected that disorganization of a skilled activity would be observed in a test involving prolonged effort at a difficult task. The disorganization having been demonstrated, the further definition of the conditions of its occurrence could be attempted and the term " fatigue " dispensed with. The experiments described in this paper prepared for this research by providing a more detailed description of the disorganization of the skilled activity than was available before, by showing that it was of two kinds, and by showing with what other mental and bodily effects each kind was associated.

The emotional disturbance, which was experienced by the subjects and of which the signs were observed, was considered to be the most important feature of the " overactivity " reaction. That emotion was provoked by the test conditions was not surprising, since subjects were obliged to carry out for a relatively long time a task in which they were unable to attain a satisfying level of performance, and the test, in this sense, constituted a " conflict " situation. It is probable that the restless and inappropriate movements, disrupting the skill of those in the " overactivity " class, were merely the reflection of the emotional disturbance and were essentially similar to the agitation and restlessness which are commonly observed in anxiety.

The effects comprising the " overactivity " reaction may be regarded as the results of a heightened expectancy, the relation of which to anxiety has been defined by Mowrer (1939). Expectancy, which implies that learned behaviour has a striving or goal-seeking character, describes the state of tension involving the anticipation of a reinforcement of a specific kind (Hilgard and Marquis, 1940). If reinforcement does not follow, expectancy may be augmented at first (Mowrer, 1940). Thence, the magnitude of anticipatory responses is increased, and anticipatory tension " spills over " into other motor channels and is displayed as restless activity. Geier and Tolman (1943), working with rats, have demonstrated a gradient of diffuse, random and restless activity, which increased as the goal was approached, but occurred only when the goal-response was prevented.

The bodily changes, observed to be associated with the " overactivity " reaction, such as flushing of the face, have a counterpart in the decline of palmar skin resistance, demonstrated in situations of " conflict " by Freeman and Pathman (1942). This effect was regarded as an indicator of alterations in the " postural substrate of activity " and to result from the vicarious discharge of " tension," when discharge in adaptive activity was prevented. Preoccupation with the task has been reported to occur in experiments involving conflict (Lewin and Zeigarnik, quoted by Lewin, 1935; Rosenzweig, 1941). Aggressive activity was to be expected from the frustration—aggression hypothesis (Miller *et al.*, 1941).

The " withdrawal " reaction was so named to conform with the field theory of Lewin, since the effects were held to represent " withdrawal out of the field of motivational conflict." Withdrawal is said by Freeman (1939) to occur when tension rises to a level at which adjustment is no longer possible and to be characterized by behaviour of less than appropriate motor requirement. This latter attribute was a feature of the reaction when it was fully developed, but, although some of the associated effects are not readily thus explained, the effects reflected in the disorganization of the skill appeared to result from a reduction of expectancy. Expectancy may be reduced after reinforcement, when the goal-response is completed, but this did not apply to the observed effects, since they followed upon the " overactivity " reaction, in which it was supposed the goal of a satisfying standard of performance was not attained. It was more likely that, in this case, expectancy was reduced or inhibited by experimental extinction.

Summary

The skilled activity required by an exercise in instrument flying was observed to become disorganized in an experimental situation which was assumed to be fatiguing. The disorganization had two phases, in each of which it was associated with characteristic changes of feeling. The two phases of the disorganization, with the associated effects, were considered to constitute two distinct reactions to the test conditions.

In the first phase, all parts of the work were

similarly affected. Although there was little or no increase in their duration, errors became more frequent and were overcorrected. Activity became excessive; movements of the controls tended to be too extensive, and there was a large increase in restless and inappropriate movements. Attention was distributed irregularly over the work and was held by aspects which had acquired a temporary urgency.

Subjects felt under strain, dissatisfied and irritable, and they were preoccupied with the test after it was finished. Signs of emotion, such as agitation and restlessness, were observed, and there were indications that muscular tonus was increased. Flushing of the face was common, and visible sweating also occurred.

In the second phase, some parts of the work were affected more than others, those regarded by the subjects as of greater importance being the better preserved. Errors became less frequent, but their correction was tardy and they were larger. Movements of the controls were often as extensive as in the first phase, but were fewer. Concentration failed and interest flagged. Some subjects were satisfied with a lowered standard of accuracy, whereas others were dissatisfied with their attainment, but made an insufficient response to remedy it, either emotionally or in organized activity, and they were apathetic and discouraged. Postural changes were variable, but flushing, or sweating, was rare.

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SOME OBSERVATIONS ON THE VISUAL FIELDS IN HYDROCEPHALUS

BY

E. B. C. HUGHES

(RECEIVED 8TH NOVEMBER, 1945)

THE value of quantitative perimetry in the diagnosis of intracranial diseases, and of intracranial tumour in particular, has long been recognized. The field defects resultant from lesions of various portions of the visual pathway have been studied in detail, and a voluminous literature has accrued on this theme. The field changes found in association with chiasmal lesions, secondary to pituitary tumours, and other parasellar masses, have been discussed perhaps more than any other aspect of this subject, not excepting the calcarine cortex, and yet scant attention has been given to chiasmal involvement from pressure by a distended third ventricle in obstructive hydrocephalus. Cheseldon in 1713, described a case in which severe flattening of the optic nerves and chiasma was present in association with hydrocephalus, and he is perhaps the earliest writer on this subject. Oppenheim (1911) states that " in hydrocephalus the middle part of the chiasma may be directly affected by the bulging of the floor of the third ventricle, and bitemporal hemianopsia may result." Wildbrand and Saengar (1913, p. 240) discuss in detail the pathological aspects of these cases, but only reproduce one visual field which shows bitemporal hemianopic central scotomata resulting from hydrocephalus. More recently, temporal defects have been recorded by Sinclair and Dott (1931), and homonymous, temporal and binasal defects have been published by Wagener and Cusick (1937) and by Weinberger and Webster (1941). The presence of binasal defects due to displacement of the optic nerves or chiasma by the distended third ventricle against the carotid arteries has been discussed by Cushing and Walker (1912). Most of their cases, however, showed advanced secondary atrophy.

In the course of careful quantitative perimetry in a large series of intracranial tumours, bitemporal visual field defects of varying form have been found frequently in association with hydrocephalus. A critical survey of these defects in different patients and a careful study of the behaviour of the defects in individual patients during the progress and regress of the syndrome have led to the belief that this field defect is of fairly constant form, undergoes a peculiar evolution, and is quite comparable to that seen in the upper temporal field in association with the pituitary tumours (Josefson, 1916). And, as in the latter case, it can be shown that apparently differing field defects are in reality but stages in a progressive process, and do not alter markedly from patient to patient. Some confusion of thought has been inevitable in writings on this subject, for patients with obstructive hydrocephalus so frequently have papillœdema at the time they seek treatment. The changes found with papillœdema are present at an early stage, and consist of enlargement of the blind spot and of the pericæcal amblyopic zone which tends to stretch out like a pointing finger towards the macular area, but seldom reaches it. The appearance of secondary atrophy, unfortunately so often seen, adds field defects of its own to confuse the issue (Fig. 1). The onset of secondary atrophy is heralded by loss of the peripheral field, usually on the nasal side, and this is a simple and total loss of the peripheral field and not characterized by depression features. Although the field defects of secondary atrophy are quite characteristic, and clearly distinguishable from those to be described, in order to minimize confusion any case showing established secondary atrophy or who developed it within a short time of perimetry has been discarded from this series.

Observations

The field defects to be described all occurred in association with hydrocephalus and distension of the third ventricle, demonstrated either by ventriculography, by direct vision during the performance of a third ventriculostomy, or by post-mortem study. As stated above, those cases in which secondary optic atrophy was present or suspected have not been included, and in no case was there any reason to suspect causes other than distension of the third ventricle for the field defects.

The earliest change noted in the visual fields was the appearance of a very small paracentral scotoma in the apex of the lower temporal quadrant. This usually appeared at about the same time in both fields, but considerable variation between the two eyes was noted on occasion. At first the scotoma would be " thin," perhaps only demonstrable by a small visual angle such as 1/2000, and at this stage the central isopters as a whole would not be affected in the lower temporal quadrant, but would merely step aside to skirt the scotoma should it cross their

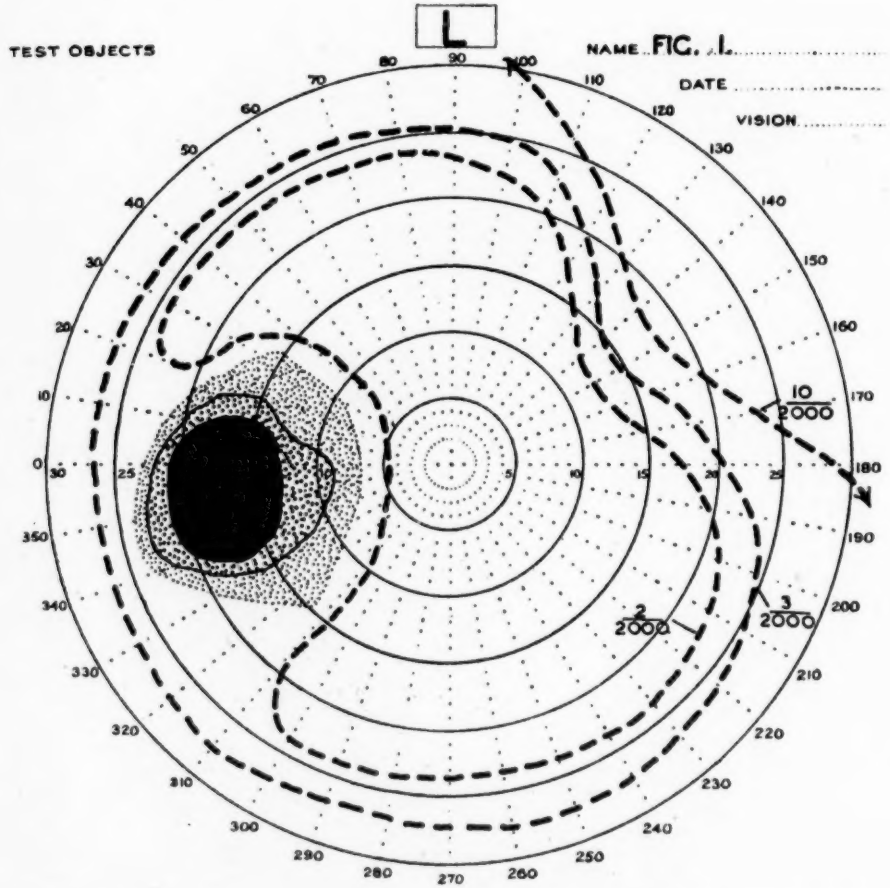


FIG. 1.—Field changes in early secondary atrophy, showing great enlargement of the cæcal area to 20/2000, and of the pericæcal amblyopic zone to 3·10/2000. There is early loss of the peripheral field in the upper nasal quadrant, but without any depression features.

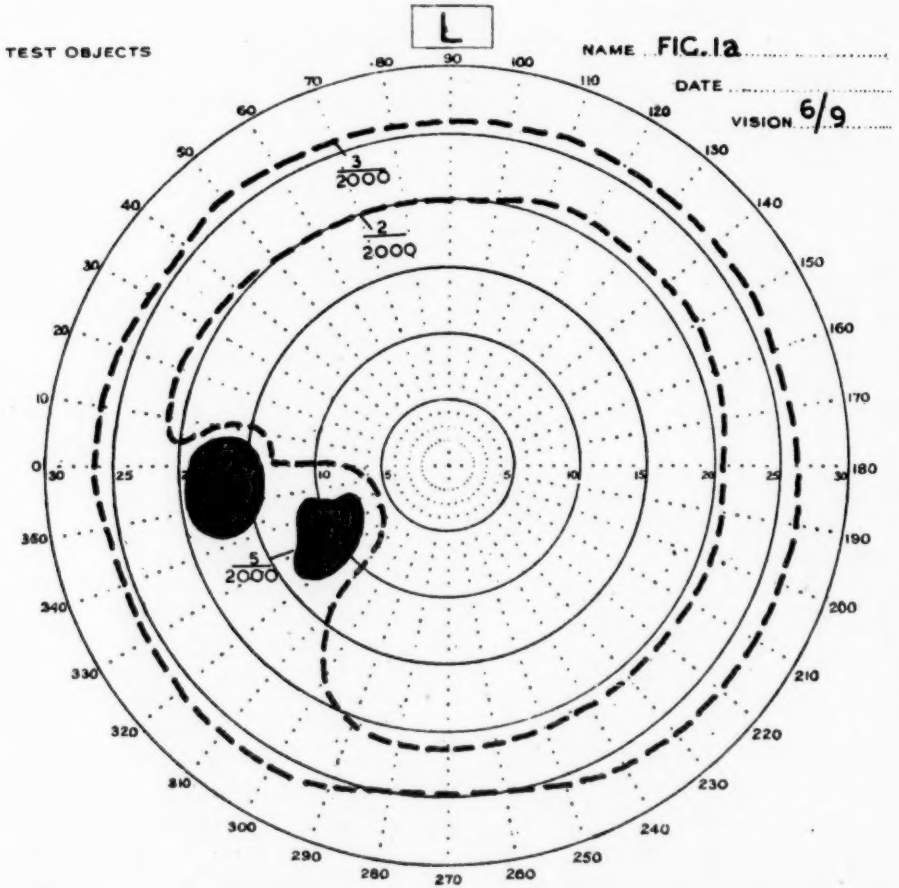


FIG. 1*a*.—Central field showing a small paracentral scotoma in the temporal field below the horizontal to 5/2000. The 2/2000 isopter is only affected locally, and the 3/2000 isopter is normal.

path (Fig. 1a). This scotoma often lay in the centro-cæcal area, usually nearer the blind spot than to fixation, and nearer the horizontal meridian than the vertical, although it has been found in many different positions. The presence of this defect seems to be a relatively early sign in dilatation of the third ventricle, and may precede other field changes by quite a long time. This field loss has not been encountered with suprasellar tumours, but this may well be due to the fact that in such cases the visual field loss has usually been well advanced by the time that treatment was sought. The scotoma then usually enlarged gradually to a small visual angle, although it has been observed that the central nucleus to a large visual angle might remain quite small in some cases. As it enlarged the adjacent isopters became involved *locally*, but at points distant from the scotoma they remained in their normal position (Fig. 2).

The next change that took place was a curious one, and one that is found in association with lesions of many parts of the visual pathway. Although it commonly followed on the scotoma development, it might rarely precede the scotoma, or, more rarely still, might be the only field change found, a scotoma never appearing. This change consisted of a depression in acuity in the affected quadrant and could be demonstrated by two characteristic perimetric features. The first feature is the better known of the two, and comprises a recession of the internal isopters. That is to say the position of, for example, the 1/2000 isopter will be most affected in the lower temporal quadrant, and the isopters of progressively larger visual angles will be less and less affected so that the peripheral isopter for, say, 1/330 may be quite normal (Fig. 3). The second feature is less well known and appreciated, and has never been clearly described, although many authors have hinted at its presence. If a white test object be placed in the normal lower nasal field, the subject will see it as a clear white round object. If the same object be placed in the affected quadrant, the lower temporal, it no longer appears as a bright white object, but will be variously described as " dull," " smudged," " greyish," " pale green," " hazy," or " not quite round." " Dirty grey " is the term most often used by patients to describe it, and this feature has in consequence been termed " greying " of the field by the author in an earlier report (Hughes, 1943). This greying of the visual field is an odd and surprising feature, and is perhaps seen more commonly in chiasmal lesions than with lesions elsewhere in the visual pathway. In the cases here discussed, it has tended to affect the whole of the

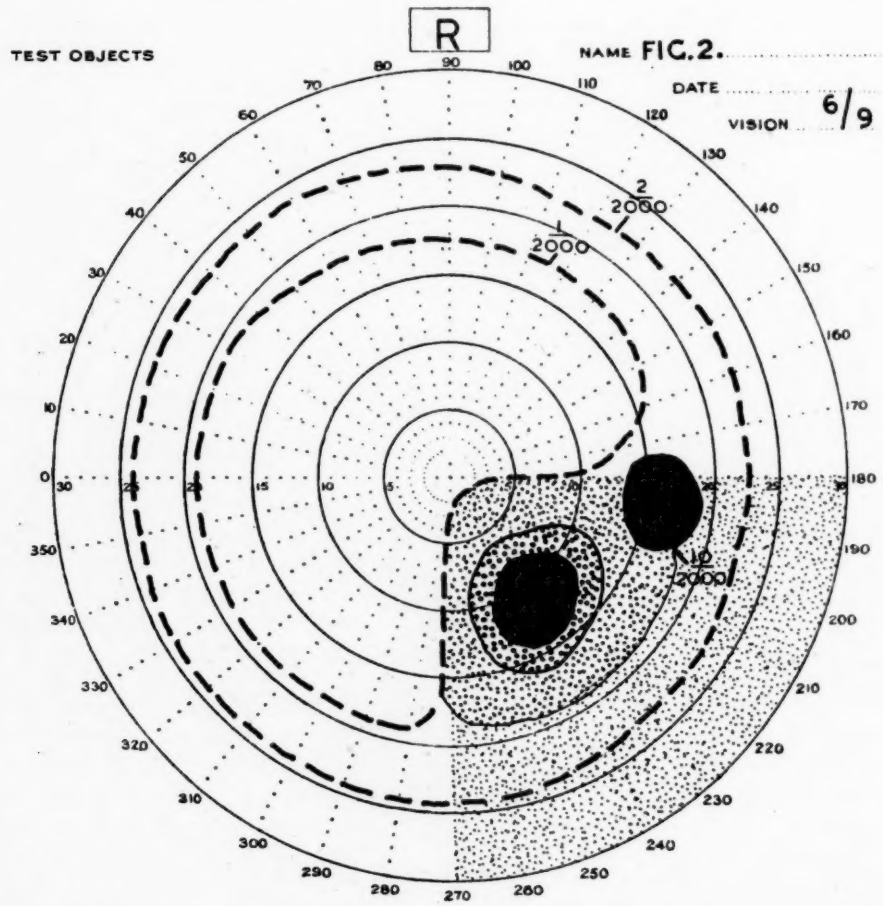
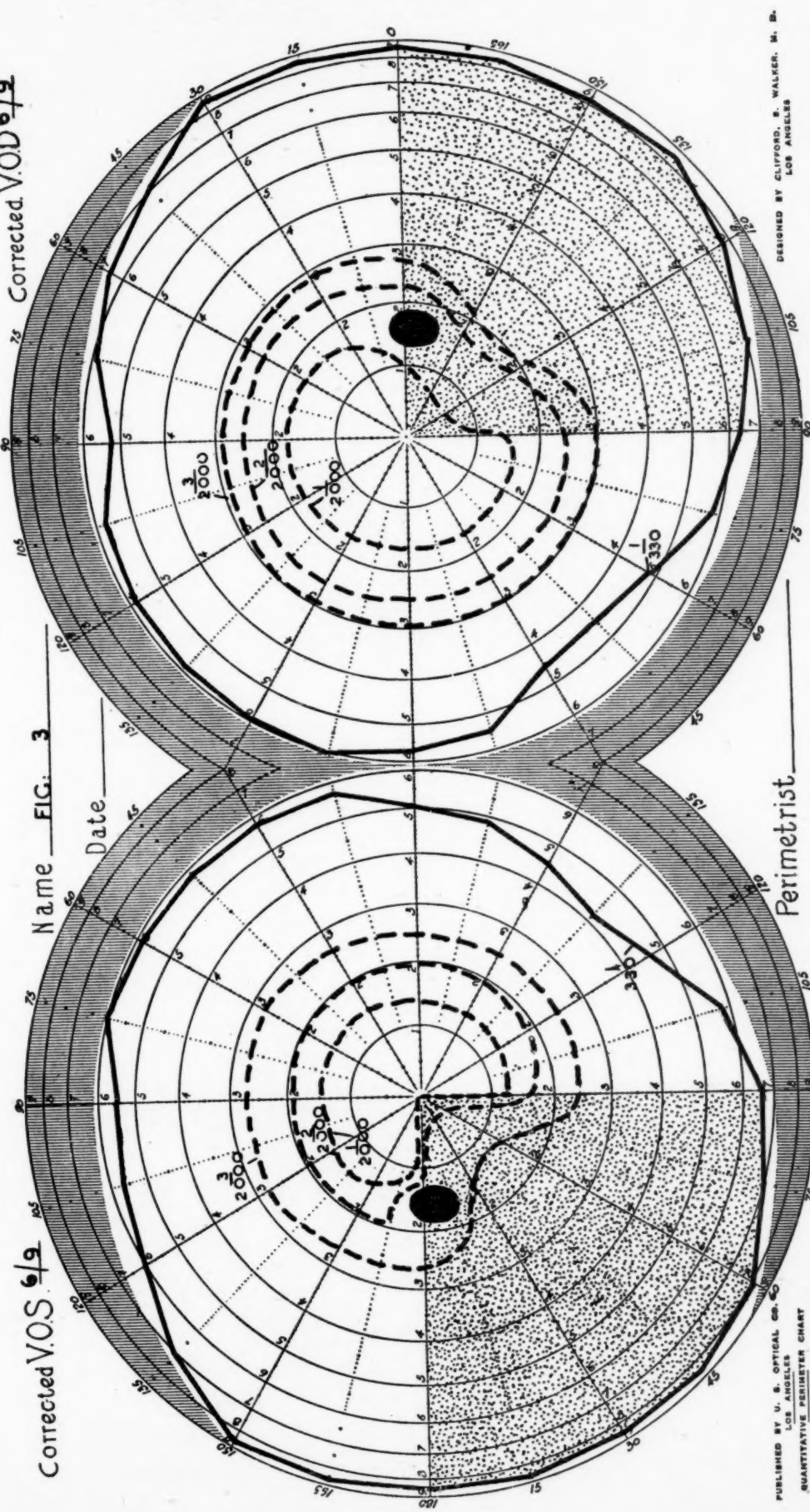


FIG. 2.—Central field showing a more advanced scotoma in the lower temporal quadrant. There is a relative scotoma to 10/2000, and absolute nuclei to 2·10/2000. The isopter for 2/2000 is unaffected.


Corrected V.O.D 6/9
Corrected V.O.S. 6/9
Name FIG. 3
Date
Perimetrist
DESIGNED BY CLIFFORD, B. WALKER, M. D. LOS ANGELES
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QUANTITATIVE PERIMETER CHART
TRACINGS AND PRINTS CAN BE MADE IN CASE COPIES ARE DESIRED

FIG. 3.—Full field chart showing depression features with greying in both lower temporal quadrants.

D

lower temporal quadrant, and that uniformly. That it should stop abruptly at the vertical meridian is hardly surprising since it is the crossed fibres that are affected, but in many cases it terminates quite as sharply at the horizontal meridian. Astonishing though this might appear, it is, nevertheless, a perimetric feature which runs true to form, for when a whole quadrant is lost in a chiasmal lesion the line of field loss most frequently runs exactly along the horizontal meridian as well as the vertical. It is most important to realize that this greying of the field is not entirely dependent upon depression of the field, for although greying is nearly always present in a depression field defect, it may occur when even the isopters of 1/2000 are quite normal (Fig. 4).

It seems necessary at this stage to make a clear-cut distinction between the two types of field defect. In the scotomatous variety, there is a localized amblyopic zone in an area of the field, which may be relative or absolute, and will affect isopters of all visual angles normally visible in this area. The isopters are affected not in virtue of the visual angle concerned, but by the presence of a scotoma in an area of the field through which they run. In a depression type of field, all isopters over a wide area of the field are affected at the same time, those of the small visual angle being naturally affected first and most severely. In its early stages there is no actual loss in the visual field, and a large test object may be seen, although dimly, over the whole normal extent of the field. When absolute field loss occurs, it takes place at the periphery of the field by an indrawing of the most peripheral isopter, so that an area of field loss appears in which no stimulus, however great, can be seen. This area may be very small at a time when there is complete quadrant loss to smaller visual angles. Paradoxically, then, this type of field loss affects the central isopters first, but total field loss first appears at the periphery.

The further progress of the field defect in the cases reported here depended on the relative proportion of scotomatous or depression features present. In the pure depression type of field, the internal isopters failed first, in the lower temporal quadrant, and were followed in regular order by the isopters of larger and larger visual angles until the most peripheral isopters were indrawn, and a state of affairs was reached in which there was actua peripheral loss of the field. This process continued until most of the lower temporal quadrant had been lost (Fig. 5). It was usually found that the extreme apex of the quadrant was spared to the extent of 2°–3°. At this stage, depression features were sometimes noted in the upper temporal quadrant, namely

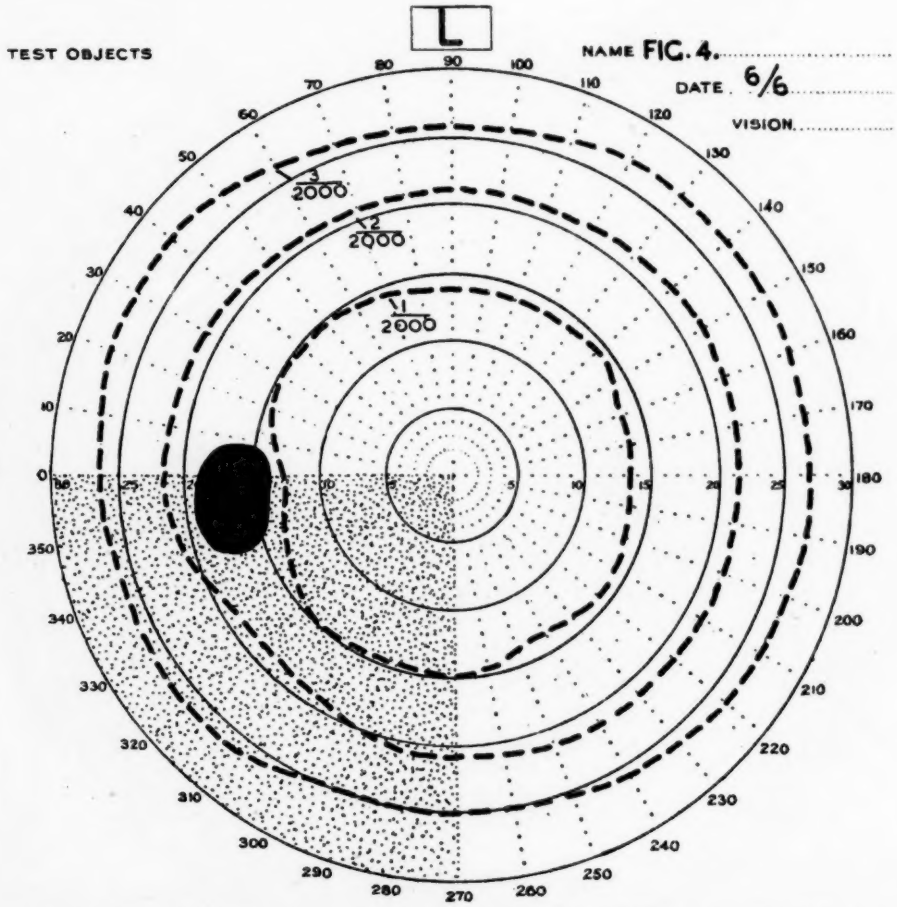

FIG. 4.—Central field showing greying of the lower temporal quadrant in the presence of normal isopters for 1·2·3/2000.

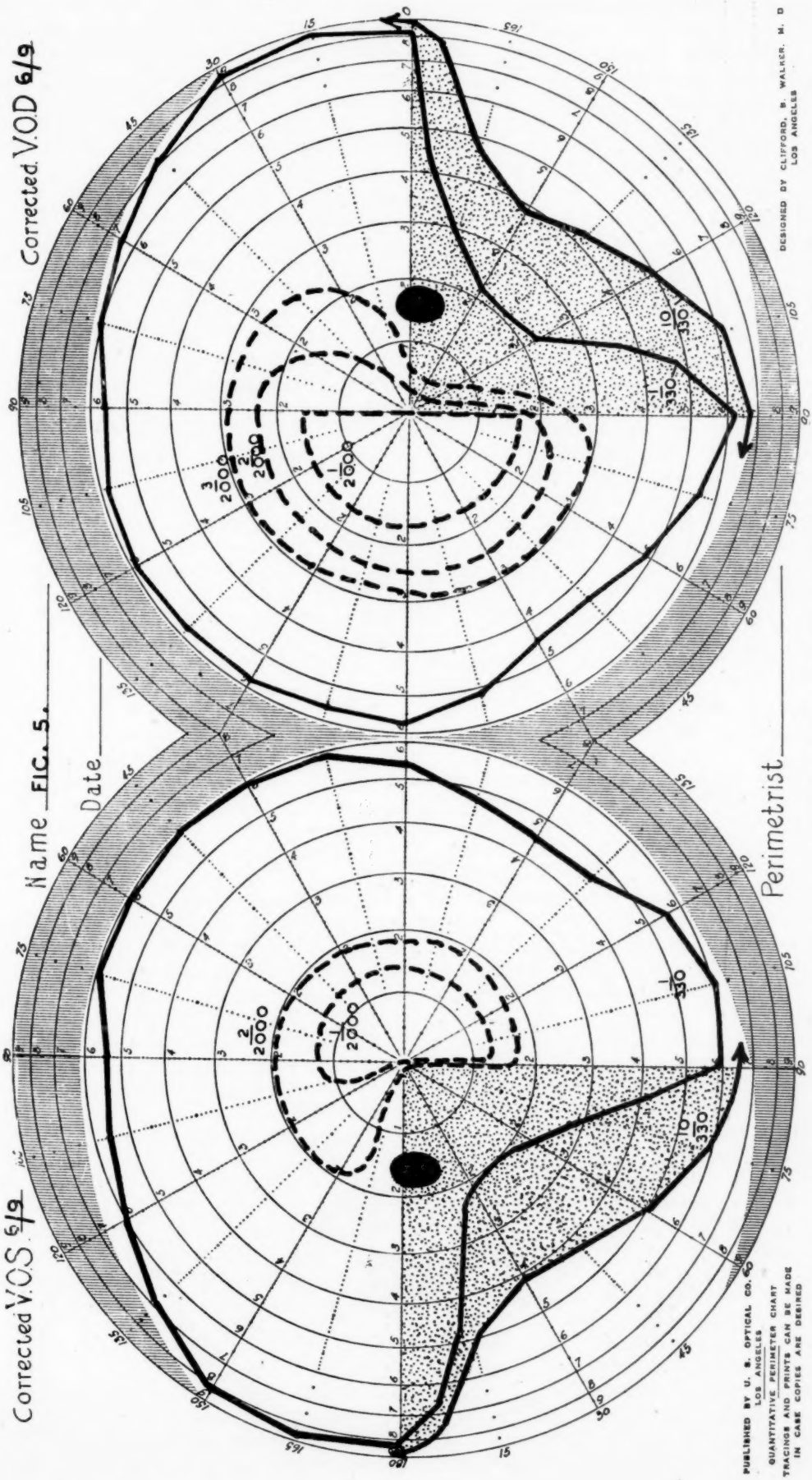
Corrected V.O.D 6/9
Corrected V.O.S 6/9
Name FIG. 5.
Date
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FIG. 5.—Same case as Fig. 3, in more advanced condition, showing actual peripheral loss of field, and commencing depression features in the upper temporal quadrant.

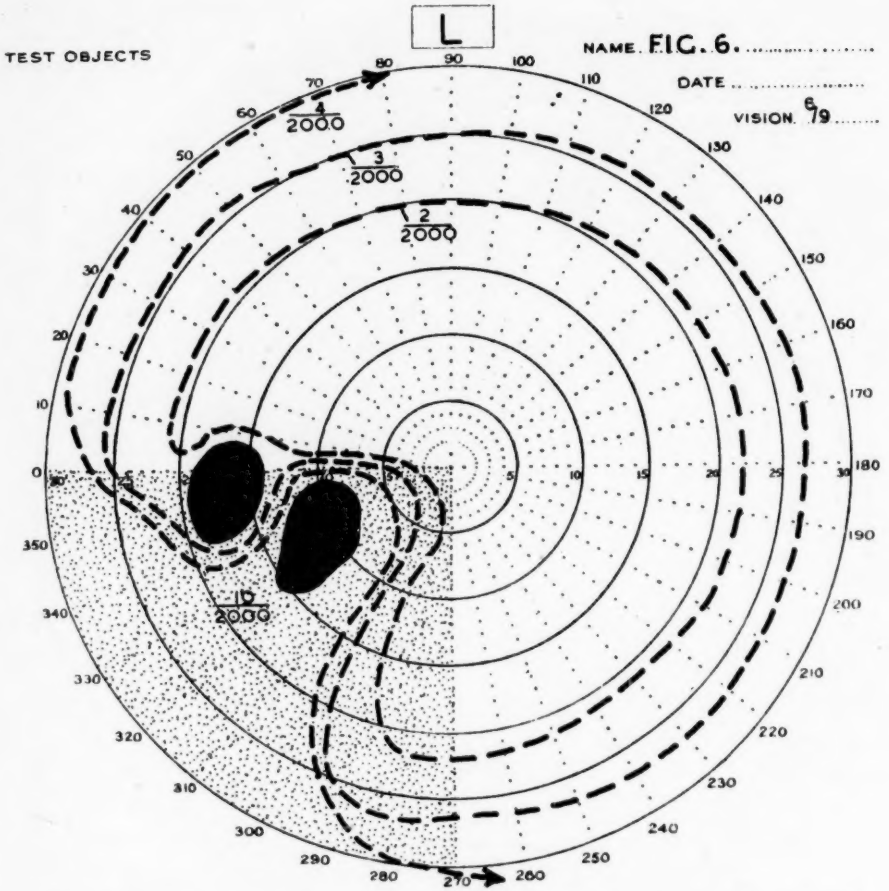

FIG. 6.—Same case as Fig. 1, more advanced. The scotoma has enlarged, and depression features have appeared with indrawing of the central isopters and greying of the affected quadrant.

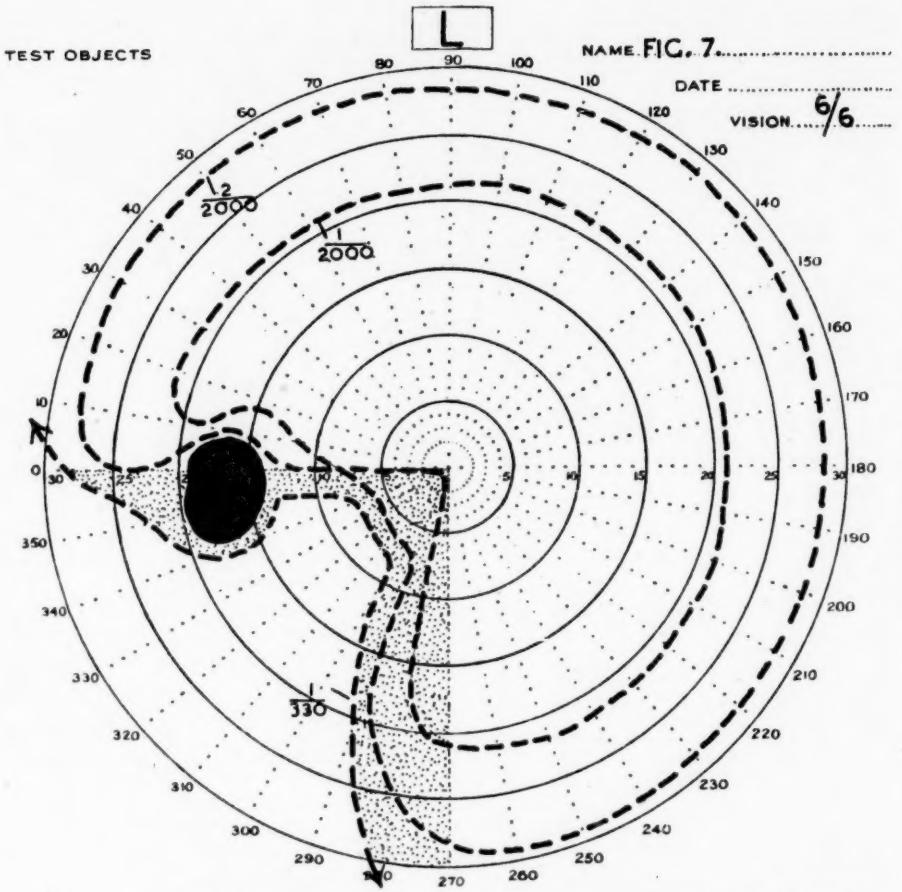

FIG. 7.—More advanced stage than Fig. 6, with actual loss of peripheral field.

an indrawing of the internal isopters, and a quadrantic greying. It was not common, however, to find this even when the lower quadrant was severely affected. Presumably, were this defect to progress, it would follow the same trend as the field in cases of pituitary tumours and result in progressive loss of the upper temporal quadrant and then invasion of the nasal field. No case, however, was encountered in this series in which the whole of the temporal field had been lost. Complete bitemporal hemianopia, in fact, seems rarely to have been observed, and many of the authors quoted have stressed this point. The question of loss in the nasal field is taken up below.

Where scotoma formation was the predominant feature, the course of events was somewhat modified. The original scotoma enlarged and came to occupy most of the lower temporal quadrant. At the same time, depression features usually appeared with indrawing of the internal isopters and greying (Fig. 6). Then the peripheral isopters became involved, either by the progress of the depression feature, or by actual enlargement of the scotoma, and an incomplete quadrant loss would be found (Fig. 7). It was not uncommon at this stage for a small scotoma to appear in the upper temporal quadrant in a position comparable to its first appearance in the lower quadrant (Fig. 8). Presumably, were the process to continue, the upper and lower scotomata might coalesce, producing an hemianopic central scotoma similar to that seen so often with pituitary tumours. Such does not seem to be the case with this type of field defect; the next stage consisted of an invasion of the fixation area at the apex of the lower temporal quadrant by the scotoma, followed by an invasion of the fixation area in the upper quadrant and finally on the nasal side of the fixation (Fig. 9).

It is clear that many different combinations of depression and scotoma might be expected to occur, but an attempt has been made here to sort out general principles underlying the process, and to stress the fact that individual variations encountered are usually stages in a progressive process rather than characteristic of the individual. The incidence of these field defects in all cases with hydrocephalus has been impossible to determine. Many have been first seen in an unco-operative state when perimetry has been impossible. In many others who might have shown such field defects at an earlier stage the perimetric picture has been so overshadowed by severe secondary atrophy that proper assessment has been impossible. Of the remaining cases in which adequate perimetry has been possible somewhat over half have shown these defects in one or other form.

Discussion

The etiology of this field defect has not seemed in doubt. All cases were hydrocephalic from obstruction at the level of the Sylvian aqueduct or below, and there was no suggestion in any case that there might have been direct involvement of any part of the visual pathway by tumour. Some of these defects, in fact, occurred in association with simple obstructions in the roof of the fourth ventricle, or in benign stenosis of the aqueduct.

That the distended anterior end of the third ventricle can press forwards and downwards on to the chiasma, and even displace the chiasma forwards, there has been abundant proof from operative and post-mortem studies, and excellent histological sections showing this have been published by Wildbrand and Saenger (1913, Plate XII and XIII, Fig. 80, 81 on p. 238). In several cases an opportunity to study the relations of the chiasma and third ventricle during life was afforded during the performance of an anterior third ventriculostomy operation. In these cases, the chiasma was often seen to be displaced forwards so greatly, that even the anterior margin of the chiasma was convex forward. The relationship of the third ventricle to the chiasma has been studied in great detail by de Schweinitz (1923) and Schaeffer (1924) and there can be no doubt that great individual variations may be found in the site of the chiasma. One might imagine, therefore, that pre- or post-fixation of the chiasma would have a considerable influence on the portion of the chiasma affected and the consequent field changes. It is well known that prefixation of the chiasma will allow a pituitary tumour to pass backwards and upwards behind the chiasma, and so give rise to central scotomatous field changes often in the lower temporal quadrant rather than the upper temporal defects more often seen. Such wide variation is not so possible in the case of pressure from a distended third ventricle, for, whatever the site of the chiasma, the normal third ventricle is always wholly above and behind it. If the chiasma is post-fixed, or in its normal position, the third ventricle will tend to enlarge against its posterior aspect, and to spread over its superior surface. This type of pressure is usually associated with the depression type of visual field defect. If the chiasma is pre-fixed, then the ventricle will tend to exert most of its pressure effects against the posterior and inferior aspect of the chiasma, and the ventricle may even appear from beneath the chiasma between the two optic nerves in front. It is in such cases that the central scotomatous changes are found, and the field defect may be very similar to that found with a pituitary tumour extending upwards behind the chiasma.

Traquair (1942) has suggested that a scotomatous field change is suggestive of activity in a chiasmal lesion, and non-scotomatous of a slowly progressing or stationary lesion. The inferences drawn above suggest that the type of field defect is dependent on the site of the lesion rather than on the activity of the process. The basis for this observation does not depend only on the half-dozen odd cases in the above series in which the position of the ventricle relative to the chiasma was known for certainty, but on a much larger series of chiasmal field defects from all causes, mostly pituitary tumours.

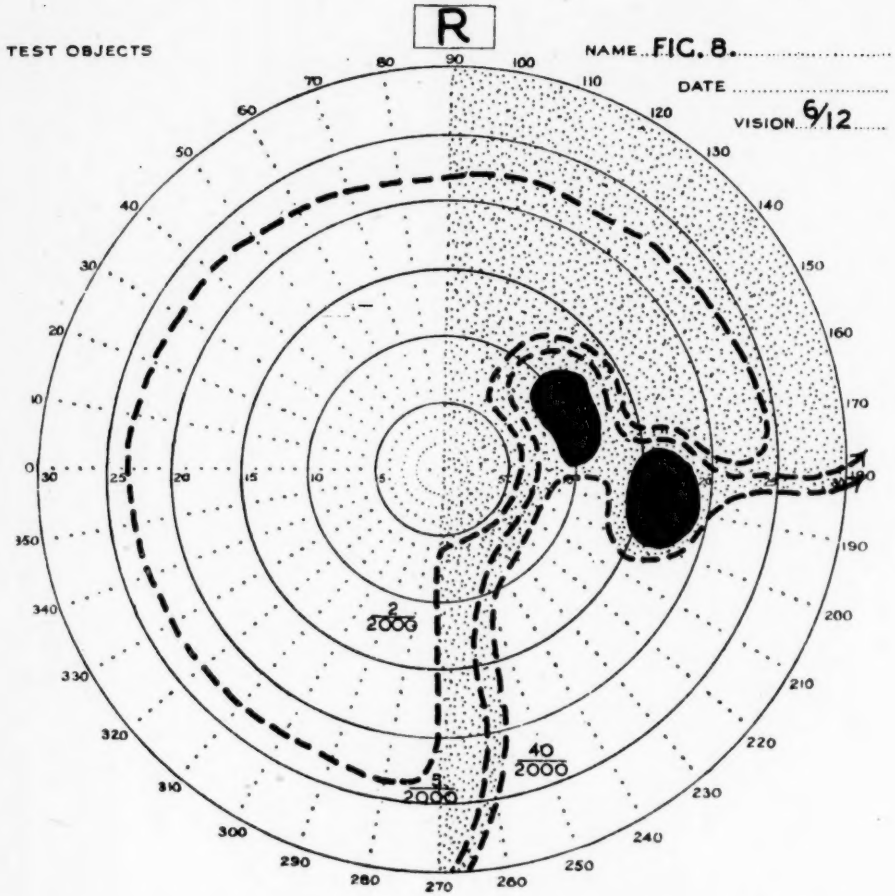

FIG. 8.—More advanced than Fig. 7, there is severe loss of field in the lower temporal quadrant, greying has appeared in the upper temporal quadrant and also a small paracentral scotoma.

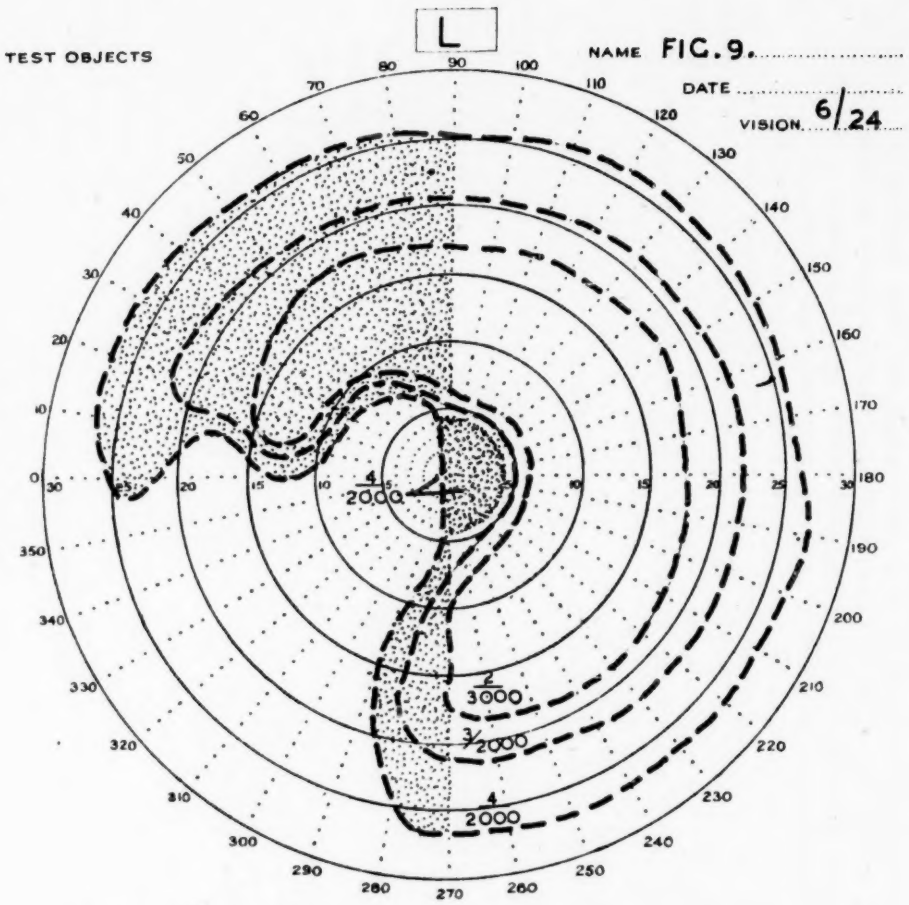

FIG. 9.—More advanced stage than Fig. 8, with severe loss of the lower temporal quadrant, loss of the whole macular area to 2·3/2000, loss of the temporal macular region to 4/2000 with a relative scotoma in the nasal macular area to this visual angle.

Great stress has been laid in the past on the relationship of normal and abnormal vessels to the chiasma, and it has been suggested that many field defects may be caused by displacement of the chiasma against adjacent vessels rather than by direct pressure from the displacing tumour. With the relatively soft pituitary adenoma post-mortem examination has shown such deep indentation of the optic nerves, chiasma or tracts by vessels that they must undoubtedly have caused field defects. In the cases under consideration, this hypothesis seems unlikely, for the distended ventricle spreads out over the chiasma and effectively protects it from the superjacent vessels, and would tend also to push it away from the subjacent posterior communicating artery. The only vessel which might conceivably play a part is the internal carotid, and displacement of the chiasma against this vessel would give a nasal type of field loss, totally different from the loss described above.

Some authors, and particularly Cushing and Walker (1912, *loc. cit.*), have stressed binasal field defects as characteristic of distension of the third ventricle. Although these authors were quite aware of the possibility of bitemporal field defects occurring, and quote Oppenheim (1911) on this subject, yet they state that bitemporal hemianopia " never seems to occur." This observation from two observers of such high repute cannot be neglected. The cases they described were a heterogeneous collection comprising hemisphere and posterior fossa tumours, and one case of fairly definite Leber's familial optic atrophy. The only feature common to them all was papillœdema and secondary optic atrophy. These authors suggested that in the " normal " consecutive optic atrophy one might expect to see an even and widespread loss of visual field, corresponding to contraction of scar tissue over the whole extent of the nerve, but that with distension of the third ventricle the chiasma is displaced outwards against the carotid vessels so that fibres from the nasal field are affected. The nasal field fibres affected by two pathological processes are, therefore, the first to show clinical evidence of damage. Paton (1909) in discussing the relationship between optic neuritis and cerebral tumour was not satisfied that secondary atrophy was invariably the cause of loss of vision in these cases, and suggested pressure by a distended third ventricle as an additional cause. He did not, however, make any observations on the type of field defect present. Secondary optic atrophy is, unfortunately, still not uncommon with cerebral tumour, but the field defects produced by this process are fairly characteristic and easily distinguishable from those of the simple hydrocephalus. In the author's experience, early loss of the peripheral nasal field is a constant feature of secondary atrophy, whatever the primary lesion may be, and is found equally often in those cases with a distended third ventricle as in those without.

Summary

1. A very brief review of the literature on field defects in association with hydrocephalus is given.

2. The progressive field changes found in this condition are described and divided into scotomatous and depression types of field defect. The essential difference between these two types is stressed.

3. The etiology of the field loss is discussed, and the effect of pre-fixation and post-fixation of the chiasma, of the relation of various vessels of the circle of Willis, and of secondary optic atrophy are discussed.

I am indebted to Mr. Harvey Jackson for permission to publish the records of many of these cases. I should like also to express my thanks to Professor Jefferson for the amount of care and time he has spent in helping me with the preparation of this paper.

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SOCIETY OF BRITISH NEUROLOGICAL SURGEONS

The thirty-second Meeting of the Society was held at the Canadian Neurological and Facio-Maxillary Hospital at Hackwood Park on 4th November, 1944, under the presidency of Mr. Norman Dott. The Meeting was attended by well over 100 visitors, including consultant representatives of all the British and Canadian Services and a large contingent of U.S. Army neuro-surgeons. Lt.-Col. E. H. Botterell, R.C.A.M.C., introduced the day's discussions on the treatment of battle casualties. Twelve papers were read, most of which have already been published or are in process of publication in Canadian, American and British journals.

BOOK REVIEWS

THE SHAPING OF PSYCHIATRY BY WAR

J. R. Rees

(London. Chapman and Hall, Ltd. Pp. 158. 10*s.* 6*d.*)

From these lectures a fair notion can be obtained of the spirit which has informed the activities of the psychiatrists of the British Army. Brigadier Rees, who moulded the shape of these activities, succeeds in putting on paper much of his convictions and experience of psychiatry in wartime, as well as the philosophy behind his constant efforts to develop an active and pervasive branch of the medical services. The first part of the book describes the steps and methods whereby the aims he set before himself were attained in the Army, and the latter part outlines the ways in which this might be applied in civil life, if the author's hopes were to be realised. These hopes, broadly painted in the final chapter of the book, are resumed in an appendix: they cover industry, selection for the professions, education, crime, social inquiry, and planning. Under this last head, the author, in the closing words of his book, insists that wartime experience has made it quite clear that the psychiatric contribution to social and political planning of the future is at least as important as any other, given the right kind of psychiatrists to make it. The successes which Dr. Rees records, in broad outline, in the earlier part of the book prevent even the sceptical reader from discounting such beliefs and hopes as the dreams of an unpractical enthusiast. There are, however, many passages which will make such readers regret that wartime restrictions have made it impossible for the author to give the evidence for his more sweeping statements—the more so, since his style, urbane and temperate though it mainly is, slips occasionally into over-protestations, such as: " without any question the value of the psychologist in war has been demonstrated so clearly that in peace there will be no question that his help will be demanded." But to most readers the book will offer a telling picture of the varied and expanding work which, under Dr. Rees's guidance and impetus, the psychiatrists in the Army were called on to perform.

TEXTBOOK OF MEDICINE

Edited by J. J. Conybeare

(E. and S. Livingstone, Edinburgh. Seventh Edition, 1945. Pp. 1164. 30*s.*)

In this textbook of medicine 224 pages of a total of 1138 are devoted to diseases of the nervous system. Following several opening pages given to a description of the general symptomatology of organic nervous diseases, the author passes to a series of admirable sketches of the symptomatology, signs and treatment of the various diseases affecting the nervous system. Undue prominence is not given to the rare diseases, yet sufficient information is available for the keen student. It is of interest to note that surgical interference, apart from alcohol injection in the treatment of trigeminal neuralgia, receives no high recommendation and little is said of partial root section as a therapeutic measure. It is indeed unfortunate that in the section allocated to the aetiology of myasthenia gravis the diagnostic test of injection of " prostigmin", a solid substance, is referred to as " four cubic centimetres of prostigmin with 1/100 gr. of atropine sulphate". Later the therapeutic doses are given in milligrammes. According to the makers this substance is supplied either in ampoules of 1 c.c. containing 0·5 mg., or in phials of 5 c.c., each c.c. containing 2·5 mg. The variability of the spelling of " prostigmin " is regrettable.

There is no doubt that the section on nervous diseases is good, adequate, comprehensive and well balanced.